ESTCP
FINAL REPORT

For

THE USE OF WETTING AGENTS/FUME SUPPRESSANTS FOR MINIMIZING THE ATMOSPHERIC EMISSIONS FROM HARD CHROMIUM ELECTROPLATING BATHS

Naval Facilities Engineering Service Center
Naval Occupational Safety and Health
1100 23rd Street,
Port Hueneme, CA 93043

August 2003

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **The Use of Wetting Agents/Fume Supressants for Minimizing the Atmospheric Emissions from Hard Chromium Electroplating Baths**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Facilities Engineering Service Center,Naval Occupational Safety and Health,1100 23rd Street,Port Hueneme,CA,93043**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**214**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

TABLE OF CONTENTS

APPENDICES:

LIST OF TABLES:

LIST OF FIGURES:

(Plus 9 annotated photographs in Appendix C)

LIST OF ACRONYMS

AFB - Air Force Base
ALC - Air Logistics Center
AMS – Aerospace Material Specification
APCDs - Air Pollution Control Devices
CAE – Clean Air Engineering
CNO - Chief of Naval Operations
CFR - Code of Federal Regulations
CIHL – Consolidated Industrial Hygiene Laboratory
DOD - Department of Defense
EPA - U.S. Environmental Protection Agency
FAA - Federal Aviation Authority
HVOF - High Velocity Oxy-Fuel
IH - Industrial Hygiene
MACT – Maximum Achievable Control Technology
MSDS – Material Safety Data Sheet
NAS - Naval Air Station
NADEP - Naval Aviation Depot
NAVAIR - Naval Air Command
NEPMV – Navy Environmental and Preventative Medicine Unit
NESHAP – National Emission Standard for Hazardous Air Pollutants
NFESC – National Facilities Engineering Service Center
NIOSH – National Institute of Safety and Health
NRMRL - National Risk Management Research Laboratory
OFS – Organic Fluorosulfanates
OSHA - Occupational Safety and Health Administration
PEL - Permissible Exposure Limit
PES – Pacific Environmental Services
PFOS – Perfluorooctane Sulfonates
QAQPS - Office of Air Quality Planning and Standards
RTI – Research Triangle Institute
USAF - U.S. Air Force
USN - U.S. Navy
WA/FS - Wetting Agent Fume Suppressant

ACKNOWLEDGEMENT

The support from the following organizations and persons are gratefully acknowledged.

Kathleen (Kappy) Paulson – Naval Facilities Engineering Service Center, Port Hueneme, CA – Project Manager
Stephen Schwartz – Versar, Inc., Springfield, VA – environmental testing, project coordination
Craig Matzdorf – Naval Air Command, Aerospace Materials Division Patuxent, MD – material testing coordination
T. David (Dave) Ferguson - EPA Risk Management Research Lab, Cincinnati, OH – regulatory and sampling advice
Glen Graham – Air Logistics Center, Tinker Air Force Base, Oklahoma City, OK – coordination of sampling activities at Tinker
Jesse Garman – Naval Air Depot, Cherry Point, NC – coordination of sampling activities at Cherry Point
Ernie Shiwanov – Naval Air Depot, North Island, San Diego, CA – data on activities at North Island

We also gratefully acknowledge funding by the US Environmental Security Technology Certification Program (ESTCP).

1. Introduction

This project demonstrates that a "third" generation wetting agent / fume suppressant (WA/FS) chemical additive to hard chromium electroplating baths reduces hexavalent chromium airborne emissions to the environment and reduces employee occupational exposures in the electroplating shop. While emissions are important, maintaining material quality for tactical equipment is paramount, and the WA/FS has no negative effect on electroplating quality or basis metals. Further, once added to the electroplating bath the WA/FS does not measurably degrade over a period of time. Also, the project demonstrates the use of WA/FS during normal, full-scale plating operations.

1.1 Background Information

Hexavalent chromium is a heavily regulated material by both the Environmental Protection Agency (USEPA) and the Occupational Safety and Health Administration (OSHA). During plating operations, the combination of mechanical mixing by aeration and electrolytic activity causes bubbles to be emitted from hexavalent chromium electroplating baths. Mist from the bubbles is then pulled into the exhaust ventilation system, and discharged to the atmosphere (usually after passing through an air pollution control device [APCD] that typically removes over 99 percent of the mist from the exhausted air stream). The relatively small amount of mist that is not captured by the ventilation system is disbursed throughout the shop into worker breathing zones, and eventually deposits on surfaces throughout the shop.

This project examines the use of one WA/FS product (Fumetrol® 140) that reduces the surface tension of the chromium electroplating bath. Reduced surface tension means reduced size of the bubbles produced. Reduced bubble size causes less misting, hence less hexavalent chromium emissions. Therefore, less chromium is exhausted to the APCD, and there are also less fugitive emissions into the plant environment, subsequently reducing employee occupational exposure. Other WA/FS products were considered but not included because their formulations were undergoing changes in the early stages of the project.

WA/FS additives are considered an inexpensive interim solution to compliance with USEPA's National Emission Standard for Hazardous Air Pollutants (NESHAP) for hexavalent chromium until the Department of Defense (DOD) and others develop alternative technologies that can substitute for hard chromium electroplating. In approximately 30% of existing hard chromium plating operations the alternatives in development cannot currently be used. WA/FS will significantly reduce emissions in those operations.

1.2 Objectives of the Demonstration

One project goal is to provide data to the regulatory arm of the USEPA to support the inclusion of WA/FS use as an acceptable alternative to the quantitative NESHAP stack emission standards for hard chromium electroplating. Such an alternative is currently available for *decorative* chromium producers. The project is designed to demonstrate that Fumetrol® 140, a WA/FS, significantly reduces atmospheric emissions during routine, full-scale electroplating operations.

It is intended to show that if surface tension is controlled to 30 dynes/centimeter or less with WA/FS, then atmospheric emissions from the hard chromium bath exhaust system are likely to comply with the NESHAP emissions limit of 15 micrograms per dry standard cubic meter (µg/dscm), which is the most stringent standard for hard chromium bath emissions (see Table 1-1 in section 1.3). This standard is based on control by APCDs (e.g., scrubbers, mesh pad mist eliminators, etc.).

A second objective is to demonstrate that there is a significant reduction in fugitive chromium emissions from the bath (i.e., emissions to the workplace). WA/FS additives are reported to reduce occupational exposures to help ensure compliance with the current Permissible Exposure Level (PEL) of 100 micrograms per cubic meter ($\mu g/m^3$) as chromium trioxide (CrO_3), which is equivalent to 52 $\mu g/m^3$ as chromium. (However, OSHA has proposed to reduce the exposure to a PEL between 0.5 to 5.0 $\mu g/m^3$ as chromium.) In any case, the project is intended to show that there is a significant drop in area emissions, which implies lower occupational exposures.

A third objective is to determine that the WA/FS does not negatively affect the integrity of the electroplating process, the hard chromium coating, or the functional properties of the plated components. Critical properties are fatigue characteristics and embrittlement. Successful evaluation requires that material testing of hard chromium-plated samples produced in baths containing WA/FS perform as well as samples treated in baths without WA/FS.

Testing occurred at Naval Air Depot (NADEP) Cherry Point, North Carolina and Air Logistics Center, Oklahoma City, Oklahoma (Tinker AFB) from the summer of 2000 through the summer of 2001. Also, relevant data were gathered from NADEP North Island, San Diego, California. North Island's electroplating shop already uses Fumetrol® 140. Since a baseline without WA/FS could not be established, North Island was not included in air emissions testing.

Air emissions testing included source emissions sampling of the ductwork (using USEPA Method 306) exiting from the hard chromium electroplating baths (i.e. prior to existing APCDs), and also occupational area sampling (using OSHA Method 215). Air emission samples were taken during eight days of testing at Cherry Point (three days without WA/FS, and five days with WA/FS in the bath), and during six days of testing at Tinker (one day without WA/FS, and five days with WA/FS). During the testing routine full-load electroplating operations were conducted.

Hard chromium product quality performance tests, per AMS QQ-C-320, include hardness, hydrogen embrittlement, thickness, adhesion and porosity. Samples were taken before and after the addition of Fumetrol® 140 at Cherry Point and Tinker. Since North Island already uses the WA/FS, the project evaluates samples generated at North Island only while using WA/FS. Fatigue evaluation was achieved by following a Limited Equivalence Fatigue test plan developed by NAVAIR. For the fatigue tests, specimens were plated at Cherry Point from tanks with and without WA/FS.

1.3 Regulatory Issues

Numerous air quality regulations at the local, state and federal levels affect the hard chromium electroplating industry. Also, OSHA regulates occupational exposure to hexavalent chromium.

In 1995, USEPA promulgated its *National Emission Standards for Hazardous Air Pollutants (NESHAP) for Chromium Emissions from Hard and Decorative Chromium Electroplating and Chromium Anodizing Tanks* (Code of Federal Regulations, Part 63, Subpart N)[1]. Under these standards, facilities that perform chromium plating must demonstrate that chromium emissions do not exceed acceptable limits, and must also satisfy monitoring, record keeping and reporting requirements. Table 1-1 is a synopsis of the current hexavalent chromium electroplating standard. It can be seen from Table 1-1 that *decorative* chromium electroplaters do not have to meet a quantitative emissions standard if they achieve a specific bath surface tension by the application of WA/FS. USEPA's Office of Air Quality Planning and Standards (OAQPS) is considering allowing the use of WA/FS additives for hard chromium electroplating as well, based on work done under the Common Sense Initiative (a joint USEPA and American Electroplaters and Surface Finishers program), and studies such as this one. However, no such regulation is currently planned or proposed in the immediate future for Hard Chromum Electroplating Emissions.

OSHA currently regulates hexavalent chromium under Title 29 CFR 1910.1000, Table Z-2, Limits for Air Contaminants. The current Permissible Exposure Limit (PEL) is a ceiling value of 100 micrograms/cubic meter ($\mu g/m^3$) as chromic trioxide (CrO_3), which equates to 52 $\mu g/m^3$ as chromium. (100 $\mu g/m^3$ is equivalent to 0.1 milligrams/cubic meter [mg/m^3]). However, OSHA was petitioned for an emergency temporary standard in July 1993 and is expected to issue a new hexavalent chromium standard shortly. A recent court case set dates for the proposed regulation and the final regulation at 4 October 2004 and 18 January 2006 respectively. The anticipated standard is expected to be between 5.0 and 0.5 $\mu g/m^3$ as chromium. This is about a 10- to 100-fold reduction below the current regulatory level. NAVSEA heavy metals studies, primarily in welding and cutting operations, show that the Navy and the commercial shipbuilding industry, in most cases, will be able to meet the 5.0 $\mu g/m^3$ value but not the 0.5 $\mu g/m^3$ value. Results of the current project suggest that this might also be the case for hard chromium electroplating bath occupational exposures when WA/FS is not used. However, when WA/FS is used, it is quite likely that DOD hard chromium operations will easily be able to meet the more stringent 0.5 $\mu g/m^3$ standard.

Table 1 – 1: USEPA Standards for Chromium Plating and Anodizing Baths

Type of Bath	Emission Limitations	
	Small Facility (<60 million amp-hrs/yr)	**Large Facility**
Hard Chromium Plating Baths		
All existing baths	0.03 milligrams/dry standard cubic meter (mg/dscm) (1.3 x 10^{-5} grains/dry standard cubic foot [gr/dscf])	0.015 mg/dscm (6.6 x 10^{-6} gr/dscf)
All new baths	0.015 mg/dscm (6.6 x 10^{-6} gr/dscf)	0.015 mg/dscm (6.6 x 10^{-6} gr/dscf)
Decorative Chromium Plating Baths Using Chromic Acid		
All new and existing baths	0.01 mg/dscm (4.4 x 10^{-6} gr/dscf) **or** Surface Tension of <45 dynes/centimeter (3.1 x 10^{-3} pounds/foot [lb_f/ft])	
Chromium Anodizing Baths		
All new and existing baths	0.01 mg/dscm (4.4 x 10^{-6} gr/dscf) **or** Surface Tension of <45 dynes/centimeter (3.1 x 10^{-3} lb_f/ft)	

The only other regulatory issue stems from a new USEPA rule (67 FR 11007, 11 March 2002, Perfluoroalkyl Sulfonates; Significant New Use Rule that could affect the use of the WA/FS tested for this project (Fumetrol® 140). The rule requires that manufacturers of perfluorooctyl sulfonate compounds notify USEPA before commencing manufacture or importing of these substances. USEPA is concerned that these compounds, which appear to be the primary active ingredient in Fumetrol® 140, may be "hazardous to human health and the environment". This rule has no immediate effect on the use of WA/FS. However, it is conceivable the rule might lead to banning or reducing the use of such compounds for certain uses. The recommended dosage of Fumetrol® 140 for hard chromium electroplating baths is only 0.25 percent. It is unlikely that such low concentration use would ever be regulated for hard chromium operations, especially since its function is to reduce significantly the environmental and occupational exposure to a known carcinogen; i.e., hexavalent chromium.

1.4 Previous Testing of the Technology

USEPA's National Risk Management Research Laboratory (NRMRL), tested Fumetrol® 140 WA/FS at Hohman Plating and Manufacturing Incorporated, Dayton, OH and several other facilities. Hohman falls under the category of a "large facility" for USEPA reporting and control technology purposes. (DOD operations fall in the same category.) Several papers, including *Use of Fume Suppressants in Hard Chromium Baths - Quality Testing* and *Use of Fume*

Suppressants in Hard Chromium Baths-Emission Testing[2,3], developed for technical and end-user publications describe the test results.

During USEPA's testing, using OSHA and National Institute of Safety and Health (NIOSH) sampling procedures, it was shown that the concentration of hexavalent chromium in the airspace directly above the electroplating bath decreased three orders of magnitude with the addition of WA/FS. During normal operating conditions, using WA/FS, workers at the tested facility were exposed to hexavalent chromium below the current permissible exposure limit of 52 $\mu g/m^3$ as chromium, but above the most stringent proposed permissible exposure limit of 0.5 $\mu g/m^3$ as chromium. No conclusions could be drawn confirming that Fumetrol® 140 will provide compliance with the anticipated OSHA standards.

Material quality testing showed that the Fumetrol® 140 had no negative effects on plating quality. In fact, adding Fumetrol® 140 tends to increase microhardness. While, some negative outcomes (e.g., pitting tests) were observed during testing, the same negative outcomes were observed from samples taken from baths not containing WA/FS. Inferior quality outcomes were attributed to poor preparation before plating.

2. Technology Description

2.1 Description

2.1.1 Theory

Wetting agents/fume suppressants (WA/FS) are defined as any chemical, added to the electroplating bath, that reduces or suppresses fumes or mists at the surface of the bath (40 CFR 63). Electroplating baths, and in particular hexavalent chromium baths emit bubbles of hydrogen and oxygen at the bath cathode and anode respectively. In fact, for hexavalent chromium electroplating baths, 85-90 percent of the electrical energy supplied to the baths produces bubbling. (The other 10-15 percent causes chromium to plate on the substrate metal.) These bubbles (and also the bubbles produced by mechanical aeration of the baths) burst as they rise to the surface of the baths, causing the production of chromic acid mist.

"Surface active" fume suppressants (also called surfactants) are added directly to chromium plating baths and are classified as either temporary or permanent. Fume suppressants are further divided into the way they reduce emissions. Foam "blankets" typically suppress the mists produced on the surface of plating baths, while wetting agents change the surface chemistry (i.e., the surface tension) of the plating baths to reduce misting.

WA/FS reduces the surface tension of a liquid. When WA/FS lower the surface tension of a plating bath, gases escape at the surface of the solution with a diminished "bursting" effect, causing less mist formation (i.e., smaller bubble size, less surface impact). WA/FS chemicals are organic compounds whose components have opposing solubility tendencies, typically an oil-soluble hydrocarbon group and a water-soluble ionic group. The "third generation" WA/FS product tested in this demonstration is Fumetrol® 140, a liquid distributed by Atotech USA, Inc., Rock Hill, South Carolina.

The "first generation" WA/FS were hydrocarbon-based with an ionic group at one end, such as kerosene or paraffin oils. The disadvantages of the first generation surfactant outweighed the benefits. The oil components were layered on the surface and carried over to the rinse tanks. Health and safety issues included possible fire hazards and dermatitis. Further, these WA/FS oxidized rapidly producing trivalent chromium and insoluble organic compounds that eventually decomposed to carbon dioxide. This behavior required frequent or continuous WA/FS additions, making them a more temporary than permanent solution. The trivalent chromium was also a bath contaminant requiring the plating bath to be replaced/regenerated more often.

In the "second generation" WA/FS, the hydrocarbon chain was replaced with a fluorinated or perfluorinated carbon chain. This WA/FS, which was first reported in the chromium plating industry in 1954, can be considered permanent since it has been found to remain stable in boiling concentrated chromic acid, and is tolerant to the highest oxidizing conditions existing at the electroplating bath anodes. The original second generation WA/FS, although chemically neutral,

was a cationic surfactant with a dihydroamine functional group. The amine group was later replaced with the sulfite group that changed the surfactant to anionic. The active ingredients in the second generation WA/FS include potassium perfluoroalkyl sulfonate, amine perfluoroalkyl sulfonate, potassium perfluoroethyl cyclohexyl sulfonate, and ammonium perfluorohexylethyl sulfonate. These WA/FS have a low solubility and become suspended causing roughness, porosity, and cracking on the chromium plate during hard chromium plating operations. Salt was added to these WA/FS compounds to improve solubility. The salt itself may have caused adverse effects on product quality.[*]

The "third generation" WA/FS (introduced in the late 1980s/early 1990s), being tested in this study, are also perfluorinated but with higher solubility and lower foaming. Supplemental chemical additives are not required to improve the solubility. Active ingredients include organic fluorosulfonate and tetraethylammonium-perfluorocytyl sulfonate. Another benefit of the third generation WA/FS is that there appears to be no adverse effect on the chromium plate, basis metal, or process equipment during hard chromium plating operations.

2.1.2 Process Description

This project demonstrates that the third generation WA/FS additive to hard chromium electroplating baths reduces hexavalent chromium airborne emissions to the environment and employee occupational exposures in the electroplating shop. Further, emissions of hexavalent chromium are expected to be low enough that regulatory agencies may not require the use of air pollution control devices (APCDs) on exhausts from hard chromium electroplating operations. (Currently, USEPA does not require APCDs for *decorative* chromium electroplating operations that use the appropriate amount of WA/FS.)

2.1.2.1 *Installation and Operational Requirements*

The process of using WA/FS to control emissions of hexavalent chromium from hard chromium electroplating baths is quite simple. It consists of adding approximately 0.25 percent by volume of the Fumetrol® 140 liquid WA/FS to a hard chromium electroplating bath (i.e., 2-½ gallons of WA/FS to a 1,000 gallon bath), and allowing a short period of time (hours) for the bath contents to reach equilibrium. This procedure effectively lowers the surface tension of the bath from above 70 dynes/centimeter (as measured by a De Nouy Ring Tensiometer) to below 30 dynes/centimeter. Additional Fumetrol® 140 is added over time as required to maintain the surface tension below 30 dynes/cm. These additions are relatively small, because the WA/FS is stable in the plating bath. Replacement is essentially for mists carried out the exhaust stack, dragout and splashing.

[*] Private e-mail from David Ferguson, USEPA, Fume Suppressants Summary, 3/22/99

2.1.2.2 D*esign Criteria*

There is no capital equipment involved with the application of WA/FS. The only criterion is that the surface tension of the bath be monitored and maintained. Monitoring requires the purchase of a De Nouy Ring Tensiometer (another less expensive surface tension measuring device is a stalagmometer). We chose the tensiometer to ensure a more accurate reading and to eliminate operational differences between test sites. The surface tension should be measured according to the regimen discussed in the decorative chromium standard shown in Table 2-1. If surface tension measurements indicate that more WA/FS is required, it should be added to bring the bath to the desired value (i.e., below 30 dynes/centimeter). Personal correspondence at the time this study was being developed indicated that EPA plans to require different surface tension values depending on the test equipment. The stalagmometer target surface tension value would remain at 45 dynes/cm and the target value using a tensiometer will be 30 dynes/cm. Since the tensiometer was used in this project, the bath surface tension was targeted to be below 30 dynes/cm. In addition, it was desired to test occupational/environmental health and safety and material quality characteristics at the lowest practical surface tension to identify potential effects on in-house air quality and on material quality of tactical equipment.

Table 2-1: Surface Tension Monitoring Protocol

Trigger	Monitoring Frequency	Test Period	Passing Criterion
New tank solution	Every 4 hrs	40 hours	No exceedances
Pass 40 hours	Every 8 hrs	40 hours	No exceedances
Pass 80 hours	Every 40 hours	Indefinite	No exceedances or solution change
Exceedance or Solution change	Start all over		

2.1.2.3 *Process Schematic and Description*

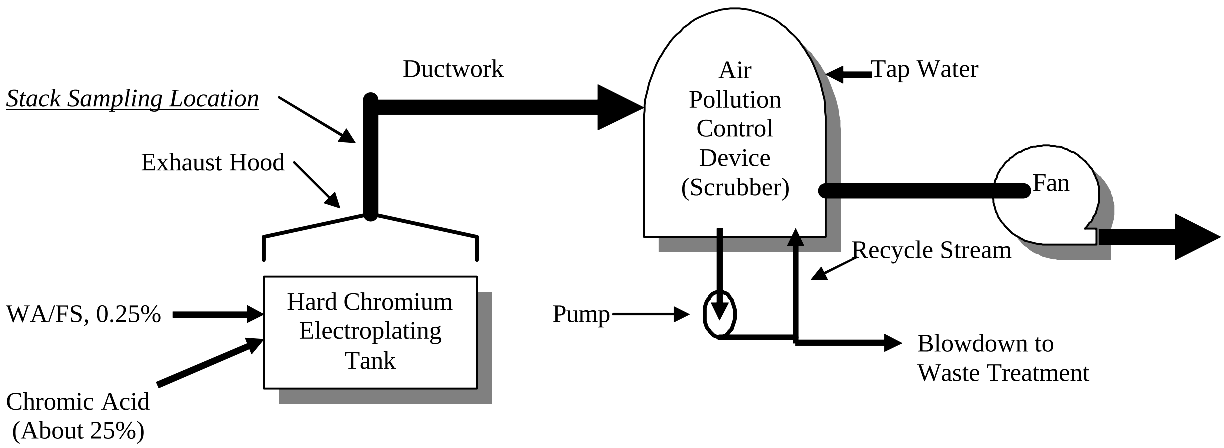


Figure 2-1: Process Schematic

As seen in the schematic, the hard chromium electroplating bath (or more than one bath) is vented to an air scrubber. Water is recycled through the scrubber to remove the chromic acid mist from the air stream. A portion of the recycled water is blown down to a wastewater treatment facility, where the chromium is ultimately removed from the wastewater as hazardous waste sludge. Note that the test point was always located between the hexavalent chromium-containing tank and before the scrubber.

2.2 Strengths and Weaknesses

2.2.1 Strengths

The advantages are that the WA/FS technology is very simple and inexpensive. Initial cost estimates are around $800 per year per 1,000-gallon bath (including the initial WA/FS addition). Cost savings are expected to occur from reduced maintenance of existing air pollution control devices (APCDs), less wear and tear on the ventilation hoods, ductwork and exhaust fans, savings in chromic acid because less chromic acid mist escapes the bath, savings in water used in APCDs (i.e., air scrubbers), and savings in the cost of treating the wastewater from APCDs. Ultimately DOD could obtain significant savings if air pollution equipment were no longer required on future plating lines.

DOD is investigating methods of replacing hard chromium electroplating with other more environmentally friendly coating methods. Other technologies are constantly being evaluated for the purposes of minimizing or eliminating the need for hexavalent chromium-based electroplating, or minimizing emissions from such plating. Thus far none of these technologies have been successfully implemented in applications that are currently served by conventional hard chromium electroplating. Some examples are:

- Tank Lids/Covers: Covering hard chromium electroplating tanks during plating operations reduces the amount of ventilation required, thus reducing the amount of contaminated air that is exhausted from the plating operation. However, this approach is not popular because it enhances the possibility of explosive situations (i.e., hydrogen buildup), and interferes with the ability to operate the plating baths on an uninterrupted basis (i.e., electroplating must cease every time the cover is removed to add a part to the bath).
- High Velocity Oxy-Fuel (HVOF) Thermal Spray Systems: This is a technology that allows the application of chromium to metal substrates through high temperature techniques. However, the application is limited to line-of-sight coatings, whereas electroplating provides for more uniform coatings. Consequently, HVOF may somewhat reduce the need for hard chromium electroplating, but is not expected to ever be able to eliminate it.
- Trivalent Chromium Electroplating: Chromium can be electroplated from a trivalent chromium bath (e.g., chromium sulfate). Trivalent chromium is much less toxic than hexavalent chromium. However, thus far, trivalent chromium techniques do not yield the quality of coating, or the rate of deposition that is available from hexavalent plating.
- Alternative Coatings: On an R&D basis, several nickel/cobalt alloys have been evaluated as alternatives to chromium coatings. Much study is still required to determine if the coating quality is as good as chromium when subject to real-world conditions.

However, NADEP Cherry Point estimates that after much of the high technology processes currently undergoing research are implemented, approximately 20-40 percent of their existing hard chromium electroplating operations will continue. This estimate is reasonable for all other DOD hard chromium plating facilities as well. Many of the high technology processes cannot plate in non-line-of-site areas such as recesses and pinch points. Therefore, even if alternative and/or high tech alternative technologies are implemented, the activity will still have a need for conventional chromium electroplating baths in the foreseeable future.

2.2.2 Weaknesses

Preliminary tests performed by the USEPA's National Risk Management Research Laboratory (NRMRL) show that there are no limitations to plated product quality while using the WA/FS additive.

However, there are anecdotal stories that WA/FS is not appropriate for hard chromium plating on cast iron since the cast iron already has significant pitting. However, USEPA tested one cast iron sample and found no effect on material quality. Otherwise there are no restrictions on types of substrate to be plated.

USEPA recently discussed the project with Delta Faucet Company, which uses WA/FS for decorative chromium plating. Delta found that cathode efficiency decreases when using fume suppressants. This is the only other negative item reported when using the newest suppressants (i.e., third generation WA/FS). The efficiency loss may slightly change the power requirements for the plating process. However, this phenomenon could not be evaluated during this study.

2.3 Factors Influencing Cost and Performance

2.3.1 Factors Influencing Cost

There are two general factors that influence the economics involved in using WA/FS to reduce emissions of hexavalent chromium from hard chromium electroplating baths: (1) the cost of implementing the WA/FS addition, and (2) the cost savings realized by the use of WA/FS. Detailed cost analysis is given in section 6.0.

The only direct costs required for implementation of the technology are the cost of purchasing the WA/FS, Fumetrol® 140, and the relatively low cost of monitoring its concentration to ensure that proper emissions performance is maintained. These activities are described in section 2.2.

More specifically, startup costs are approximately $800/bath, including an initial WA/FS charge costing about $300 to make up the bath initially (800 gallon bath with 2 gallons of WA/FS). Shop personnel require approximately two hours to familiarize themselves with the material safety data sheets and the material addition practices. The material is in liquid form and is added to the bath via mixing. Mixing ingredients into baths is not a new procedure for shop personnel.

As part of the startup costs each site must purchase and use a tensiometer at a cost of approximately $2,500 to perform accurate surface tension measurements. During the life of the tensiometer (well over ten years), it is expected that the tensiometer platinum wire test ring will be replaced at a cost of $260 every two years. Laboratory personnel will require approximately 4-6 hours to familiarize themselves with the tensiometer test method. Further, there will be an additional cost for the laboratory personnel to take periodic tensiometer measurements.

There may also be a small amount of documentation/computer-related cost to identify those parts electroplated using a WA/FS amended bath, as well as documentation to track the addition of the WA/FS. It is also likely that some time will have to be spent incorporating the use of WA/FS into hard chromium electroplating specifications, both at the shop level, and at other levels within DOD.

Initially, there are indirect costs related to the use of WA/FS. One of those costs is related to monitoring the quality of the parts electroplated in a WA/FS bath (relative to those that are not).

Other potential indirect cost *savings* will be based on a determination by individual shops as to whether existing APCDs can be "turned off" (i.e., turning off water feed to scrubbers, and not having to treat scrubber blowdown) because compliance with atmospheric emission regulations is achieved by using WA/FS alone. For new shops, the purchase of APCDs (i.e., scrubbers) may not be required, saving at least $200,000 in capital cost per shop (based on the cost of the Cherry Point hard chromium bath scrubber system). It is also expected that between $800 and $3,200 per bath per year will be saved in chromic acid costs, because the WA/FS will ensure that acid that had escaped the bath as mist, through the ventilation system, will remain in the baths. Ventilation system ductwork/fans as well as other plating shop equipment may last longer because there is less chromic acid to corrode/decompose them.

There are also likely to be occupational health benefits to plating shop workers because concentrations of chromium will be reduced from their pre-WA/FS levels. The cost avoidance of reducing hexavalent chromium exposure cannot be quantified since cancer manifests itself only after a long latency period.

2.3.2 Factors Influencing Performance

The only significant factor influencing the performance of the WA/FS appears to be its concentration/surface tension. Concentration of WA/FS is proportionate to the depression of the surface tension. Even though the target surface tension for this study was 30 dynes per centimeter or less, performance equivalent to 30 dynes/cm was achieved at surface tensions as high as 34 dynes/cm (which was the highest surface tension value occurring during the tests in which WA/FS was present) - (see section 5.1.1).

It is likely that bath temperature will also influence emissions, because surface tension usually decreases as temperature increases. However, the temperature parameter becomes somewhat academic, since all hard chromium electroplating baths are usually kept in the same temperature range (typically about 120 - 150ºF).

The design of the bath ventilation system probably influences the amount of mist that is entrained in the exhaust gasses versus the amount that falls back into the bath or escapes into the shop. Regardless, during testing at Cherry Point and Tinker, even though the baseline (i.e., without WA/FS) emissions were significantly different between the two facilities, the controlled emissions (i.e., with WA/FS) from both facilities were extremely low (see section 5.1.2).

With respect to electroplated product quality, it can best be said that there is probably no statistical difference in product quality whether or not WA/FS is in use (see section 5.1.4).

3.0 Site/Facility Description

3.1 Background

After obtaining a list of Army, Air Force and Navy bases that perform electroplating, contact was made with the plating engineering departments operating at all three service branches.

Telephone conversations with the various electroplating facilities engineers indicated that Naval Air Depot (NADEP) North Island, San Diego, California, has satisfactorily used Fumetrol® 140 to reduce emissions since 1998. However, their target surface tension level is unclear. Reports range from 25 to 40 dynes/centimeter. Further, Naval Air Systems (NAVAIR) has not tested the Fumetrol® 140 for material integrity. Nor has NAVAIR approved the use of the Fumetrol® 140.

NADEP North Island made their decision to use Fumetrol® 140 after experiencing a temporary shut down for shop repairs approximately five years ago. They transferred their workload to an electroplating job shop that used Fumetrol® 140. The Federal Aviation Authority (FAA) had approved the job shop to electroplate new and reworked parts for several DOD prime contractors. Based on that FAA approval, North Island's shop and engineering management made a decision to use the additive. After a Temporary Engineering Investigation, North Island incorporated the product into their Local Process Specifications.

At the time of site selection, NADEP North Island was in the process of redesigning their electroplating shop, including the hard chromium lines. They were also still in the process of obtaining a renewed air emissions permit. Therefore it was decided to forego air emissions testing (stack and occupational exposure) at North Island. However, their materials quality testing data is being evaluated.

NADEP Cherry Point, Havelock, North Carolina was also interested in implementing WA/FS use if NAVAIR approves of the use in hard chromium baths. Cherry Point was chosen to serve as NAVAIR's test site for this study.

Hill AFB evaluated Fumetrol® 101, a second generation WA/FS, with unsatisfactory results and at the time of site selection were disinclined to try the new generation, Fumetrol® 140. However, later discussion (after validation began) with other Hill AFB staff indicates that they are extremely interested in this generation of WA/FS and await the ESTCP test results.

Tinker AFB typically electroplates engine parts that are not subject to the same stresses and mechanical performance requirements as structurally critical parts such as landing gears. They were willing to participate in this study and served as the Air Force test site.

Participation was solicited at several Army posts. However, they appear to be satisfied with their progress in reducing hexavalent chromium emissions using their current technologies. Watervliet Arsenal's gun barrel plating operation is an entirely closed loop system (i.e., it has no wastewater discharge). Their APCD has a 95% efficient first stage and polishers in the three remaining stages. They passed a Maximum Achievable Control Technology (MACT) test at

95% rectifier capacity and did not need additional emission reduction. Phone calls to other Army installations proved equally unsuccessful.

To keep the project manageable, emissions' testing was limited to one Navy and one Air Force shop that had expressed interest in participating (i.e., Cherry Point and Tinker). Electroplating for the material quality testing took take place at both facilities, and also at North Island. Work at all three shops is typical of the rework operations performed at DOD facilities, in contrast to production operations performed in a prime contractor's shop. Part configurations change from day to day in a rework shop while a production shop tends to plate the same type of part day after day.

Since selecting the three DOD sites interest has been expressed by Boeing, St. Louis, Missouri, who has been involved with using Fumetrol® 140 for chromic acid anodizing (in fact Boeing led the way for this to happen and validated its use for MIL-A-8625). Boeing is very interested in seeing how Fumetrol® 140 works with hard chromium plating. NAVAIR approval of the WA/FS will lead the way for Boeing to use it for original equipment manufacturer (OEM) parts on important NAVAIR platforms like the F/A-18E/F.

3.2 Site/Facility Characteristics

Within DOD, there are at least nine major facilities that have hard chromium electroplating operations:

- NAVAIR – Cherry Point, North Island, and Jacksonville
- Air Force – Tinker, Ogden, and Hill
- Army – Corpus Christi, Watervliet, and Anniston

The NAVAIR facilities have three to eight hard chromium electroplating baths each. If it is assumed that each of the above facilities has six baths, then there are at least 54 baths within DOD that would be amenable to the WA/FS technology. In addition there are a multitude of such facilities in the private sector.

The hard chromium electroplating facilities/baths included in this project for emissions testing purposes are:

- Naval Aviation Depot, Cherry Point, NC - Tank # 155, and
- Air Logistics Center, Tinker Air Force Base, Oklahoma City, OK - Tank # 222

3.2.1. Naval Aviation Depot, Cherry Point

The NADEP Cherry Point electroplating shop contains 50 tanks. Of these tanks, five are chromium electroplating baths. All five tanks are active, and contain between 422 and 810 gallons capacity. They exhaust into one MAPCO four-stage polymer mesh pad scrubber, rated at 40,000 cubic feet per minute (cfm). Tank 155, the emissions of which are being tested in this study, is an 800-gallon bath with about eight inches of freeboard, and a surface area of about 21.5 square feet. About 3.2 square feet of lip vent along one long side of the bath provide

ventilation. See Appendix C for photographs of Tank 155, and the fume scrubber for emissions from hard chromium electroplating operations.

There are, in total, approximately 100 tanks in the electroplating shop. Cherry Point has the capability for type I, II, and III anodizing; and nickel, silver, cadmium, and tin plating. They have recently implemented tin-zinc and zinc-nickel plating and chemical-milling capacity. They plate landing gear and aircraft components for the AV-8B, H-53, H-46, C-130, C-2, and P-3 aircraft. Currently they are implementing a High Velocity Oxy Fuel Coating (HVOF) system as a line-of-sight chromium replacement.

3.2.2 Air Logistics Center, Oklahoma City (Tinker)

The ALC-OKC shop contains 202 process tanks not including the masking and demasking tanks. There are six active hard chromium baths; all have a 1,466-gallon capacity. Tank 222, the emissions of which are being tested in this study, has about 7-½ inches of freeboard, and about 26.8 square feet of surface area. About 2.7 square feet of lip vents along both long sides of the bath provide exhaust ventilation. See Appendix C for photographs of Tank 222. In addition to the hard chromium tanks there is one chromium etch tank and five chromium rinse tanks. There are also three process tanks designated for chromate conversion.

There are 35 baths on the chromium plating line alone. The chromium line exhausts to one of two scrubbers, one for chromium emissions, and the other for acid/alkaline processes (e.g., acid etch, chromium strip, alkaline cleaning, electrocleaning, etc.) in the shop. The Tinker facility was rebuilt in the early 1990s and is a well-planned facility.

3.2.3 Naval Aviation Depot, North Island

NADEP North Island's electroplating line consists of 77 process tanks. There are two chrome rinse tanks and an acid etch activation tank. Although not available for testing, North Island has six chromium electroplating baths, five of which are active. They exhaust into one MAPCO five-stage composite mesh pad scrubber. The MAPCO system consists of four composite-mesh pads (stages I, III, IV, and V) with chevron-type blades in stage II. Due to renovations at North Island, air emissions sampling could not be schedule around their compliance sampling requirements. See Appendix C, Figure 9 for photograph of North Island scrubber system (which is similar in function to the scrubbers at Tinker and Cherry Point).

4. Demonstration Approach

4.1 Performance Objectives

The primary project objective was to provide data to the regulatory arm of the USEPA supporting the inclusion of WA/FS as a maximum achievable control technology (MACT) for hard chromium electroplating. Such an alternative is currently available to decorative chromium operations. The project was designed to demonstrate that a WA/FS reduces atmospheric emissions during routine electroplating operations. The intent was to show that if the WA/FS keeps the surface tension at or below about 30 dynes/centimeter, atmospheric emissions (i.e., stack emissions) from a hard chromium electroplating bath would remain below the most stringent hexavalent chromium regulatory limit of 15 micrograms per dry standard cubic meter (µg/dscm) (see section 1.3). Consequently, WA/FS additives are proposed as an effective alternative to mechanical air pollution control devices (APCDs) such as mesh pad mist eliminators.

A second objective was to demonstrate that there is a significant reduction in fugitive emissions from the bath. Fugitive emissions increase the occupational health exposures of the workers in the shop. WA/FS additives are reported to reduce occupational exposures below the current Permissible Exposure Level (PEL) of 52 $\mu g/m^3$ as chromium, but may not be able to reduce the exposure below the most stringent anticipated PEL of 0.5 $\mu g/m^3$ (see section 1.3). The intent was to show that there is a significant drop in fugitive emissions that leads to lower occupational exposures. However, the demonstration project configuration prevented performance of personnel sampling on the individual workers. Stationary air samples were taken instead. Stationary samples probably overestimate exposure, because they remain near or at the source of emission for the entire monitoring time. In addition, actual workers do not spend all their time at the source.

The third objective was to certify that WA/FS does not negatively affect the integrity of the electroplating process, the hard chromium coating, or the functional properties of the plated components. Critical properties are fatigue characteristics and embrittlement. Hard chromium is plated on platform-critical components at DOD facilities. Successful evaluation requires that materials electroplated in hard chromium baths treated with WA/FS perform as well as materials treated in baths without WA/FS.

4.2 Physical Setup and Operation

Figures 1 through 8 of Appendix C show the hard chromium electroplating baths and emissions sampling equipment used at Cherry Point and Tinker. At Cherry Point, the exhaust ductwork for the bath sampled (Tank 155) is routed through the basement, beneath the shop floor. The duct sampled is a 20-inch diameter fiberglass reinforced duct that runs horizontally through the basement. Two 2-½ inch sample ports were drilled in the duct for sampling purposes, 90-degrees apart on the duct cross-section. The sampling ports were about eight feet from the nearest upstream restriction (a 90-degree bend in the ductwork), and about four feet from the nearest downstream restriction (another bend in the ductwork). At Tinker, the 22-inch fiberglass ductwork from the bath sampled (Tank 222) runs vertically up toward the ceiling. The two

sampling ports were also located 90-degrees apart from one another, about 6-½ feet above the nearest upstream restriction (the converging section of the exhausts on both long sides of the bath), and over seven feet from the nearest downstream restriction (a 90-degree bend).

Industrial hygiene (IH) sampling (i.e., ambient shop air sampling) was performed at both Cherry Point and Tinker. Some of the samplers used are shown in Figure 6, Appendix C. Samples were typically taken: (1) a few inches above the surface of the baths in two locations for each bath, (2) at the breathing zone directly in front of the baths, also in two locations, and (3) at the breathing zone a few feet in either direction from the baths. At each of the sampling locations, one or two samples were taken during each sampling day. If one sample was taken, it was taken continuously for about eight hours. When two samples were taken at a location, each sample was taken for approximately four hours.

Eight days of sampling were conducted at Cherry Point. The first, second, and fourth days (11 July, 12 July, and 15 Nov 00) were sampled with no WA/FS in the bath. During the other five days (21 Sep, 16 Nov, 13 Dec 00, 27 Mar, and 17 Apr 01), WA/FS was present in the bath at the following respective surface tensions (in dynes/cm): 33, 23, 23, 27, and 27. For the first sampling day (11 July 00) there was a polyethylene shield placed around the front and sides of the bath, about four feet high (a permanent metal plate formed the fourth side). The purpose of the shield was to segregate Tank 155 from the rest of the shop environment. However, it was later agreed that the shield presented an unrealistic situation, and was deleted from subsequent sampling events.

Six days of sampling were conducted at Tinker. The first day (12 Sep 00) there was no WA/FS in the bath. During the other five days (11 Oct, 8 Nov, 6 Dec 00, 31 Jul 01, and 1 Aug 01) WA/FS was present in the bath at the following respective surface tensions: 34, 27, 30, 28, and 28. In order to get a second day of IH sampling at Tinker while no WA/FS was in the bath (i.e., another baseline set of IH samples), a set of IH samples was taken on the 1 Aug 01 sampling date in and around Tank 214 instead of Tank 222. (Tank 222, which contained WA/FS, was sampled on 1 Aug for atmospheric emissions only; i.e., stack emissions.) Tank 214 is identical in its size and operation to Tank 222, but did not contain WA/FS.

During all sampling events chromium electroplating of actual production parts or of “dummy” parts was continuously conducted. Dummy parts were used to increase the load on the tank when actual production parts were unavailable.

4.3 Sampling Procedures

In general, sampling procedures were conducted in accordance with Appendix D Table 1, and in conformity with the *Quality Assurance Plan in the Technology Demonstration Plan, 15 October 2000, Appendix E*[4].

Air pollution emissions tests (i.e., stack tests in the ductwork between baths and the APCDs) were conducted using USEPA Method 306, *Determination of Chromium Emissions from Decorative and Hard Chromium Electroplating and Anodizing* Operations[5] (60 FR 4963, 25 January 1995) sampling trains (basically a modified USEPA Method 5 train). Method 306 is the

conventional test for total and hexavalent chromium analysis for point source air emissions. The sampling equipment was leased and/or purchased from Clean Air Engineering (CAE), Palatine, Illinois. Calibration of appropriate portions of the sampling equipment was conducted by CAE prior to each testing event. Each emissions test was taken during a two-hour period, using "isokinetic" sampling techniques mandated by Method 306. (Isokinetic means that the velocity of the gases being drawn into the tip of the stack sampling probe is exactly equal to the velocity of the gases in the exhaust system ductwork.) Three 2-hour emissions tests were conducted during each sampling day.

Briefly, in the Method 306 sampling train, exhaust emissions are removed from the stack using a glass nozzle (a 3/16 inch diameter nozzle was used for all testing except: for the first run on 11 Jul 00 at Cherry Point a ¼ inch nozzle was used; for the third run on 31 Jul 01 at Tinker a 1/8 inch nozzle was used; for all three runs on 1 Aug 01 at Tinker a ¼ inch nozzle was used). During each 2-hour test the sampling nozzle was repositioned every 7-½ minutes to another sampling location (as prescribed in Method 306), for a total of 16 sampling positions. Gases passing through the nozzle entered a glass probe liner (about 3 feet long), and then entered a glass collection system consisting of four impingers in series. The first and second impingers that the gases entered each contained 100 milliliters (ml) of 0.1 "normal" (N) sodium hydroxide (about 0.4% sodium hydroxide). The purpose of these impingers is to absorb any chromic acid mist. The third impinger was empty (to catch any liquid carry-over), and the fourth impinger contained a weighed amount of silica gel (about 200 grams) to remove all traces of moisture from the gas stream. During sampling, all four impingers are placed in a container filled with ice to condense moisture. The gases exiting the fourth impinger are routed to a metering box through a rubber umbilical cord. The metering box contains the appropriate hardware to: measure the gas flow through the sampling train; measure the velocity pressure in the stack (which is related to the stack gas velocity); control the gas flow rate through the sampling train (to maintain isokinetic conditions); and, measure the temperatures at various locations in the sampling train. To determine the amount of chromium (hexavalent or total) in the sampled air stream, the liquid from the first three impingers is mixed with liquid obtained from rinsing all the sampling train glassware. (Triple rinsing was done on the glass probe nozzle, glass probe liner, and the Teflon® umbilical cord connecting the liner to the first impinger. Double rinsing was done on all other glassware.) The resulting mixture is analyzed for chromium concentration. That concentration, along with the total volume of liquid (impinger contents and rinse water) are used to determine the total chromium mass captured during the sampling event. The value for mass is combined with the volume of air sampled to derive the concentration of chromium in the air stream. As noted earlier, three samples, one from each two-hour test, were sent to the analytical laboratory for each sampling day. (The laboratory used was Research Triangle Institute, Research Triangle Park, North Carolina.) In addition, one field blank was included for each sampling event. (The blank was a sample containing only 0.1 N sodium hydroxide solution.)

As appropriate, the results for each sampling day were obtained by averaging the data from each of the three tests taken that day. The testing schedule is shown in Appendix D, Table 3.

IH area sampling was conducted using OSHA Method 215 with the most recent modifications, *Hexavalent Chromium in Workplace Atmospheres*[6]. During each test day (see Appendix D,

Table 3 for test dates), samples were taken in three locations: a few inches above the surface of the baths, at the breathing zone directly in front of the baths, and at the breathing zone a few feet in either direction from the baths. As noted in section 4.2, at each of the sampling locations one or two samples were taken during each sampling day. If one sample was taken, it was taken continuously for about eight hours. When two samples were taken at a location, each sample was taken for approximately four hours. Samples were taken using Gillian Aircon 520AC pumps (Gillian is now owned by Sensidyne), operated at about 2.1 liters per minute.

Personnel monitoring was considered for evaluation of occupational exposures. However, as noted, area monitoring was conducted instead. Due to site limitations (one bath was monitored per shop), personnel sampling is not appropriate. Several publications warn that area sampling cannot be extrapolated to indicate personnel sampling results. However, *A Strategy for Assessing and Managing Occupational Exposures*[7] states, "They [area samplers] can be used to measure emissions from process equipment or background levels of an environmental agent." The reference then goes onto discuss the number of samples needed for personnel sampling but not area sampling. It suggests a minimum of six random samples in a similar exposure group. The same six sampling locations at each bath were sampled during each sampling day (except for 1 Aug 2001 at Tinker – see the last paragraph of section 4.2). Since the locations of the samplers were essentially the same for each sampling event, more controlled conditions were realized then if personnel monitors were used.

The area samples are time-weighted averages. For chromium, there are no intermittent sample techniques, such as colorimetric indicator tubes. A previous ESTCP project evaluated a real-time monitoring device, based on spark induced breakdown spectrometry (SIBS) for hard chromium evaluation. SIBS technology is still in the development stage and using it would add significant costs to the study since it must be used by the manufacturer's technical staff.

Appendix E contains samples of forms used in the field to record the test data for both stack emissions and IH sampling. Appendix E also contains step-by-step procedures for the stack sampling, and chain-of-custody sample transmission forms.

Material quality testing was conducted for: (1) hydrogen embrittlement, (2) hardness, (3) porosity, (4) adhesion, (5) thickness, and (6) fatigue. Except for fatigue testing, all testing complied with SAE Aerospace Material Specification (AMS) QQ-C-320, *Chromium Plating Electrodeposited*[8]. The standard test includes ASTM Methods listed in Appendix D, Table 2. Limited equivalence fatigue testing is based on NAVAIR requirements and is detailed in Appendix F.

- Notched round bar specimens used for hydrogen embrittlement testing, were made from 4340 steel and purchased from Dirats Laboratories. One lot of hydrogen embrittlement coupons from each electroplating source is included in work at the Patuxent River Laboratory to assist in validating the rising step load technique.

- The Vickers Hardness test method was used to determine coating hardness. Samples from Cherry Point and Tinker were run with and without WA/FS.

- Porosity tests were conducted on coupons from Tinker and Cherry Point, both with and without WA/FS. Coupons were also tested from North Island, with WA/FS. (North Island does not hard chromium electroplate without WA/FS, so no coupons electroplated without WA/FS could be processed.)

- A bend-to-break adhesion test was used to evaluate the quality of adhesion of the chromium to the substrate. Five random samples of the original sets of 1-mil thick coatings from Cherry Point (with and without Fumetrol® 140), Tinker (with and without Fumetrol® 140), and North Island (with Fumetrol® 140) were tested.

- Thickness is a criterion that measures how close to the requested thickness is from sample to sample, and also shows the uniformity of the coating. For each coupon and average of three measurements were taken.

- Fatigue specimens were designed by NAVAIR and Metcut per ASTM E 466 and ASTM E 606, manufactured by Metcut, and plated by NADEP Cherry Point. High-strength steel alloys 300M and Aermet 100 and corrosion-resistant high-strength steel alloy PH13-8 were used in the evaluation. They represent a good cross section of alloys for rotary and fixed wing components in the aerospace and defense community.

As noted in Section 4.2 and in Appendix D, Table 3, a polyethylene barrier was erected on the first sample day at Cherry Point. Its purpose was to segregate the hard chromium bath emissions from other facility fumes, so that the samples taken just above the bath surface, and the samples taken at the breathing zone in front of the bath would not be effected by other shop fumes. However, it was concluded, after discussion with NIOSH that the barrier is not necessary and may prevent observing the realistic effects of actual shop operations such as adjacent operations and cross drafts from open doors. Consequently, the barrier was never used beyond the first day, and only at Cherry Point.

After initial baseline testing without WA/FS (i.e., Fumetrol® 140) at both shops (i.e., Cherry Point and Tinker), the WA/FS was added to the baths, attempting to reach a surface tension value of less than 30 dynes/cm. (See Appendix C, Figures 7 and 8 for visual difference between baths with and without WA/FS.) However, Cherry Point was only able to achieve a surface tension of 33 dynes/cm for the first day of testing with WA/FS (21 Sep 2000) – see section 9.1 for an explanation. Consequently, the bath contents at Cherry Point were removed, and replaced with fresh contents. Baseline tests were repeated with the new contents (i.e., without WA/FS) on 15 Nov 2000, after which WA/FS was added, and all subsequent testing at Cherry Point was done with WA/FS. At Tinker, baseline testing was done on 12 Sep 2000. All subsequent testing was done with WA/FS. (See Appendix D, Table 3 for the sampling schedule.)

4.4 Analytical Procedures

Research Triangle Institute (RTI), Research Triangle Park, NC analyzed the stack samples using USEPA Test Method 306 (which describes both the stack sampling and the sample analytical methodology).

Industrial Hygiene samples (in-plant air samples collected on filters) were analyzed by the Naval Environmental Health Center, Consolidated Industrial Hygiene Laboratory (CIHL) at Navy Environmental & Preventative Medicine Unit #2 (NEPMU 2), Norfolk VA. NEPMU 2 holds an AIHA Accreditation (laboratory #102170, Certificate #58, Accreditation expires 01/01/2003) for industrial hygiene testing of metals. The in-plant air samples were analyzed according to OSHA 215. The analytical method is similar to the analytical method required by USEPA Method 306.

The Becker Laboratory at Patuxent River MD, NAVAIR's Aerospace Materials Division's main laboratory, and the Materials Engineering Laboratory, NADEP NI, San Diego conducted the materials testing. The American Association recognizes Becker Laboratory for Laboratory Accreditation (A2LA) for compliance with ISO 9001, *Quality Systems - Model for Quality Assurance in Design, Development, Production, Installation and Servicing*. All samples handling and testing at Patuxent River laboratory is ISO 9001 compliant. Appendix D, Table 1, 2, and 4 outline the test methods.

For materials testing, there were no major deviations or modifications from standard methods for either laboratory analysis or field-testing. Any significant deviations from the standard sampling or analytical protocols are described in section 5. Material performance was judged against control coatings plated from hard chromium solutions without WA/FS. Performance, equivalent or better than controls is required for implementation. QQ-C-320B provides allowable performance limits for each test. Fatigue values are based on NAVAIR Structures Division requirements and data from other sources such as the development of High Velocity Oxy Fuel (HVOF) Coating.

5. Performance Assessment

5.1 Performance Data

There are five types of performance data that were developed in conjunction with this study:

- surface tension
- stack emission data (i.e., chromic acid mist ventilated to the environment outside the shop),
- industrial hygiene data (i.e., chromic acid mist in the areas surrounding the plating bath),
- data relating to the material quality of the parts electroplated while WA/FS was in use, and
- other data, such as the amount of WA/FS constituents in the stack emissions and scrubber wastewater.

These data are presented and described in the following sections.

5.1.1 Surface Tension

Surface tension measurements were taken to approximate the requirements for a new bath as discussed in section 2.1.2.2, *Design Criteria.* For three of the days at Cherry Point and one day at Tinker the chromium electroplating baths were in the "baseline" condition (about 72 dynes/cm); i.e., no WA/FS was added to the baths. For the other days, the baths contained WA/FS at concentrations sufficient to adjust the surface tension of the baths to between 23 and 34 dynes/centimeter. The target surface tension for test conditions was below 30 dynes/cm.

5.1.2 Stack Emissions Data

Stack emissions were sampled and analyzed on eight separate days at Cherry Point, and six days at Tinker. Three two-hour samples were extracted from the exhaust ductwork during each sampling day. The results of those sampling events are summarized in Table 5-1 in terms of milligrams of both hexavalent and total chromium per dry standard cubic meter of air (mg/dscm). In addition, Figures 5-1 and 5-2 graphically present the sampling results. For comparison purposes, the current USEPA National Emission Standards for Hazardous Air Pollutants (NESHAP) for hard chromium electroplating, for shops larger than 60 million ampere-hours per year (which all DOD shops are expected to be) is 0.015 mg/dscm. (The limit for *decorative* chromium shops is 0.01 mg/dscm **or** a surface tension of less than 45 dynes per centimeter.) All of the sampling and analysis data from each day of testing at Cherry Point are summarized in Tables 5-8 through 5-13 at the end of section 5. For Tinker each day's testing data are summarized in Tables 5-14 through 5-18.

The only significant deviation from Method 306 test requirements occurred during the testing at Cherry Point on the 15th and 16th of November 2000. For all six of those test runs the isokinicity of the tests were out of the desired 90 – 110 percent range. The isokinicity for those six tests ranged from 81.7-85.0 percent. A foreign particle became lodged in the gas flow tubing after the

sampling equipment had been calibrated by CAE (the equipment owner), but prior to the test. For all other testing, at both Cherry Point and Tinker, isokinicity was 91.9-103.1 percent.

Additionally, it was noted that a basement door was opened during the glassware rinsing phase of the second stack test at Cherry Point on 27 Mar 01. At that time a significant breeze blew constantly through the sampling/rinsing area. The chromium concentration data for the second test on that day is higher than the other two tests (0.0539 mg/dscm as opposed to 0.0356 and 0.0349). This higher reading may have been influenced by chromium-containing dust contaminating the samples during rinsing.

Table 5 – 1: Summary of Chromium Concentrations in Stack Emissions (mg/dscm)

CHERRY POINT

Sampling Date	Surf. Tension (dynes/cm)	Hexavalent Chromium				Total Chromium			
		Sample # 1	Sample # 2	Sample # 3	Average	Sample # 1	Sample # 2	Sample # 3	Average
7/11/00	*72*	*n/a*	*6.32*	*0.737*	*3.529*	*n/a*	*6.804*	*0.853*	*3.829*
7/12/00	*72*	*3.13*	*0.912*	*1.37*	*1.804*	*4.06*	*0.919*	*1.56*	*2.180*
9/21/00	33	0.0418	0.0299	0.0216	0.0311	0.0482	0.0367	0.0237	0.0362
11/15/00	*76*	*1.49*	*1.30*	*1.26*	*1.35*	*1.57*	*1.31*	*1.21*	*1.36*
11/16/00	23.1	0.0446	0.0482	0.0678	0.0535	0.0431	0.0473	0.0678	0.0527
12/13/00	23.4	0.0170	0.0273	0.0233	0.0225	0.0193	0.0289	0.0243	0.0242
3/27/01	27	0.0313	0.0533	0.0276	0.0374	0.0356	0.0539	0.0349	0.0415
4/17/01	27	0.0215	0.0153	0.0204	0.0191	0.0218	0.0163	0.0209	0.0197

	Hexavalent Chromium	Total Chromium
Average Without WA/FS:	**2.228**	**2.457**
Average with WA/FS:	**0.0327**	**0.0348**

NOTE: n/a indicates that no parts were being electroplated during test number 1 on 11 July 00

TINKER

Sampling Date	Surf. Tension (dynes/cm)	Hexavalent Chromium				Total Chromium			
		Sample # 1	Sample # 2	Sample # 3	Average	Sample # 1	Sample # 2	Sample # 3	Average
9/12/00	*72*	*0.516*	*0.286*	*0.347*	*0.3833*	*0.645*	*0.333*	*0.443*	*0.474*
10/11/00	34	0.00818	0.0104	0.00624	0.0083	0.00890	0.0125	0.0111	0.0108
11/8/00	27	0.00870	0.00715	0.00295	0.00627	0.00896	0.00642	0.00299	0.00612
12/6/00	30.5	0.0234	0.0186	0.0106	0.0175	0.0240	0.0215	0.0125	0.0193
7/31/01	27.5	0.106	0.0204	0.0337	0.0534	0.109	0.0217	0.0397	0.0568
8/1/01	27.5	0.0242	0.0314	0.0242	0.0266	0.0271	0.0344	0.0262	0.0292

	Hexavalent Chromium	Total Chromium
Average without WA/FS:	**0.383**	**0.474**
Average with WA/FS:	**0.0224**	**0.0245**

NOTE: *Italicized and shaded* rows represent baseline sampling (i.e., without WA/FS).

Figure 5-1 - CHERRY POINT TOTAL CHROMIUM EMISSIONS CONCENTRATION

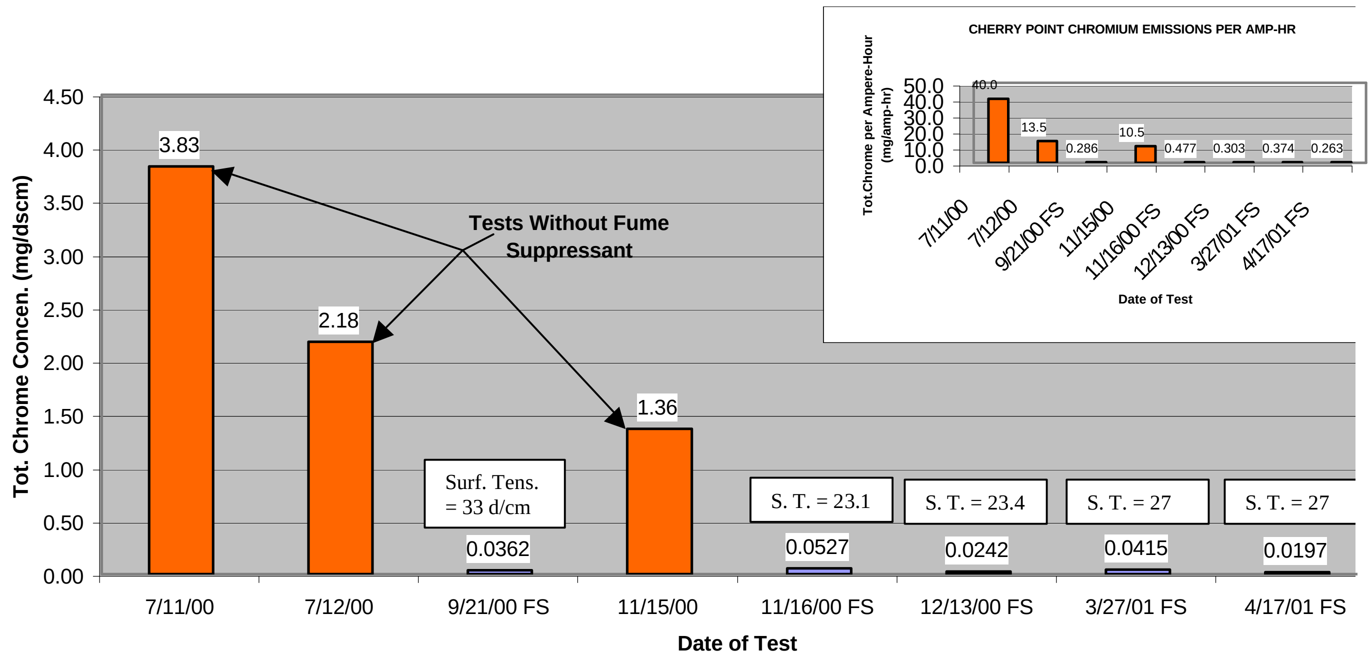
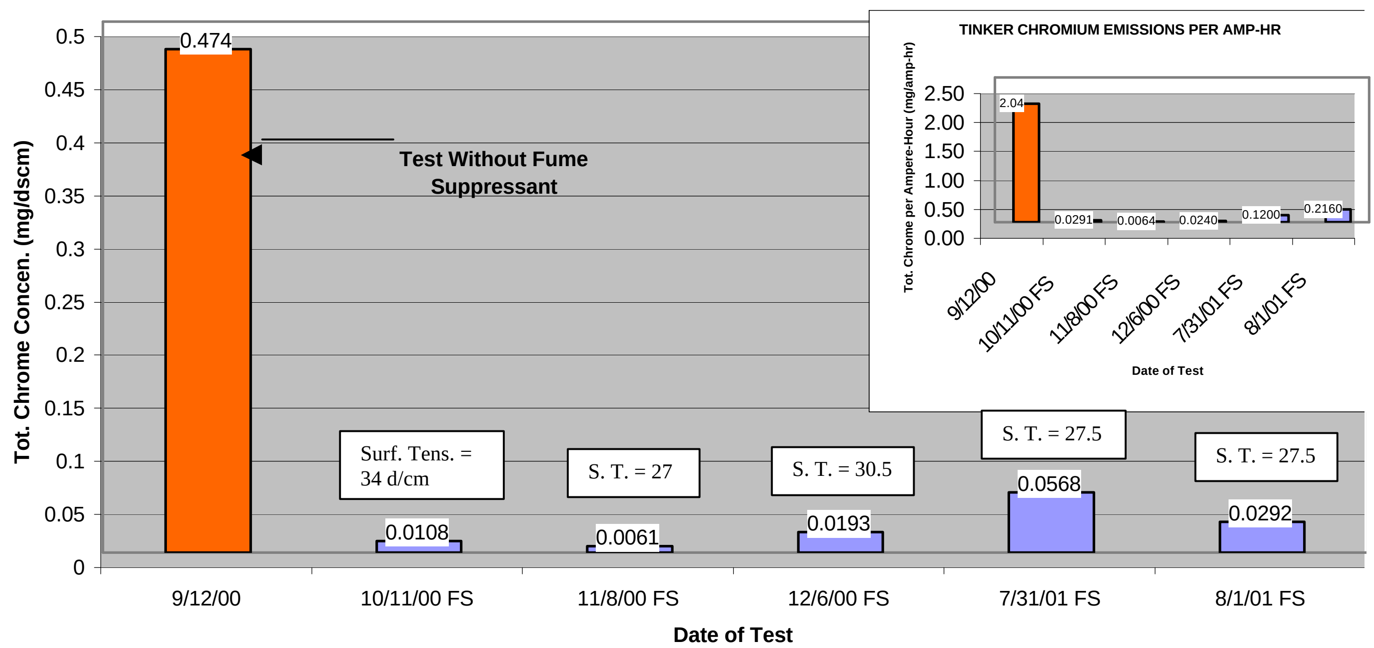


Figure 5-2 - TINKER TOTAL CHROMIUM EMISSIONS CONCENTRATION



5.1.2.1 *WA/FS Effectiveness and Level of Compliance*

It becomes immediately obvious, when reviewing the summary data in Table 5-1 and Figures 5-1 and 5-2 that using WA/FS causes a dramatic decrease in the concentration of total and hexavalent chromium from stack emissions. At Cherry Point the average reduction in concentration of total chromium was about 70-fold. At Tinker it was about 20-fold.

However, when comparing the emissions data to the current USEPA NESHAP standard of 0.015 mg/dscm, the Cherry Point average data with WA/FS for total chromium is 0.0348 mg/dscm, and the Tinker average data with WA/FS for total chromium is 0.0245 mg/dscm. Both would be out of compliance if they did not have air pollution control devices (APCDs) downstream of the sampling points.

Stack sampling was also performed at the North Island facility by Pacific Environmental Services (PES) in December 2000. Those data show that the average of two 2-hour stack tests *with* WA/FS in the electroplating bath, taken *upstream* of their air scrubber, were 1.7 milligrams per dry standard cubic meter (mg/dscm) of hexavalent chromium (a much higher concentration than the Cherry Point and Tinker data taken with WA/FS). The average of three 2-hour tests *with* WA/FS, *downstream* of their scrubber was 0.00097 mg/dscm. The downstream results are not comparable to the Cherry Point and Tinker data though, because the emissions downstream of the scrubber represent not only the effect of WA/FS, but also the effect of the air scrubber.

Data are also presented in graphs in the upper right-hand corners of Figures 5-1 and 5-2 for the emissions as a function of the electroplating load; i.e., mg of chromium per ampere-hour (mg/amp-hr). The results are also dramatic with respect to the reduction in emissions with WA/FS as compared to without WA/FS. For Tinker there is some question about whether the amp-hr meters were providing the correct readings. Therefore, some of the ampere-hour emissions data for Tinker may be incorrect.

5.1.2.2 *Hexavalent Versus Total Chromium*

There has been controversy in the scientific community with respect to what portion of the emissions from hard and decorative hexavalent chromium-based electroplating is hexavalent chromium. Both total and hexavalent chromium were reported for each stack test in this study. The data show that 57 percent of the tests had hexavalent chromium concentrations that were greater than 90 percent of the total chromium concentration. Thirty-one percent of the tests had hexavalent chromium concentrations that were between 80 and 90 percent of the total chromium concentrations. For the remaining 12 percent of the tests hexavalent chromium was less than 80 percent of the total. Note that analysis of plating bath contents performed on two baths at Cherry Point, two baths at Tinker, and one bath at North Island, show that the chromium in the plating baths is essentially 100% hexavalent chromium (see section 5.1.5.2).

5.1.2.3 *The Influence of Exhaust Volume and Velocity*

It can be noted from Table 5-1 that the emissions at Cherry Point are generally a higher concentration than those at Tinker (about 5 times higher without WA/FS in the bath, and about 1.5 times higher with WA/FS). Table 5-2 compares: the surface areas of the baths that were tested at each site (square feet); the average exhaust flow (dry standard cubic feet per minute); the freeboard (inches), the area of the exhaust intakes (square feet); the average exhaust volume per unit of bath surface area (cubic feet per minute per square foot); the average exhaust intake velocity (feet per minute); chromium concentration in the plating bath (percent); and, exhaust configuration.

Analysis of Table 5-2 does not lead to any definitive explanation for the difference in concentrations of chromium in the exhaust at Cherry Point versus Tinker. Table 5-2 does however, show the following relationships: (1) the exhaust volume at Tinker averages 13 percent higher than Cherry Point, suggesting additional dilution at Tinker, and (2) the concentration of hexavalent chromium in the bath at Tinker is about 17 percent lower than the bath at Cherry Point (at least on the days that the single samples were taken from each bath). Both these facts would support the observed higher concentration of chromium in the exhaust at Cherry Point (but not nearly as high as the differences described in the above paragraph). However, one might also assume that the exhaust system at Cherry Point does not capture fumes as effectively as Tinker because there is only one lip vent at Cherry Point, and because the exhaust intake velocity is lower at Cherry Point. This would lead one to conclude that there should be a lower concentration of emissions at Cherry Point than at Tinker.

Table 5-2: Influence of Exhaust Parameters on Emissions Concentration

	Bath Surface Area (ft^2)	Average Exhaust Volumetric Flow (dscfm)	Freeboard (inches)	Exhaust Intake Area (ft^2)	Exhaust Volume per Unit Surface Area (cfm/ft^2)	Exhaust Intake Velocity (fpm)	Hexavalent Chromium Concent. in Bath (%)	Exhaust Configuration
Cherry Point	21.5	6,350	8	3.22	295	1,970	15.1	"Pull"-only system. One lip vent on back (long side), with back wall.
Tinker	26.8	7,160	7-1/2	2.65	267	2,700	12.6	"Pull"-only system. One lip vent on each long side. Stand-alone bath.

5.1.3 Industrial Hygiene (IH) Data

Table 5-3 presents the data from IH engineering sampling. IH samples were taken concurrently with the stack testing at Cherry Point and Tinker. Samples were taken in three locations: (1) a few inches directly above the sampled bath liquid surface ("In Tank"), (2) directly in front of the sampled bath near the breathing zone ("Near Tank Breathing Zone"), and (3) a few feet from the sampled bath near the breathing zone ("Remote Breathing Zone"). It would be anticipated that the most concentrated samples would be those taken above the liquid surface, and that the least concentrated would be those "remote" samples taken a few feet from the bath. In fact this was the general trend for all testing *except* at Tinker during the baseline tests (i.e., tests without WA/FS in the bath).

Each value in Table 5-3 represents an average of two data points unless otherwise noted. Shaded values represent baseline samples (i.e., when no WA/FS was in the bath). Average concentrations for all testing are shown at the bottom of Table 5-3, both for the baseline condition, and when the baths contained WA/FS. As noted above, the trend is clear from the averages that the hexavalent chromium concentrations decrease as the sampling location becomes more remote (except for the baseline testing at Tinker).

It is also clear that the concentrations of chromium are much less when WA/FS is in use than when it is not (again with the exception at Tinker for samples taken in the breathing zone near the bath). In fact, for the samples taken a few inches from the liquid surface ("In Tank"), the improvement when WA/FS is in use is more than 20-fold. It is theorized that the improvement is not as dramatic at the breathing zone locations (and is in fact reversed for the noted Tinker "Near Tank" samples) because the concentrations are very low at those locations to begin with, such that the influence of other facility chromium-containing baths is significant. In fact, all concentrations of hexavalent chromium measured during IH sampling were far below the current OSHA Permitted Exposure Limit (PEL) of 52 $\mu g/m^3$ (as chromium), even those taken directly over the liquid surface. With respect to the most stringent *anticipated* OSHA standard of 0.50 $\mu g/m^3$, the only samples that exceeded that proposed standard were samples taken directly over the liquid surface when WA/FS was not in use (i.e., the baseline condition).

As noted above, the trends are reasonably clear that (1) using WA/FS lowers occupational exposure to hexavalent chromium, and that (2) the further away one gets from the tank surface, the lower the hexavalent chromium shop air concentration becomes. The notes on Table 5-3 indicate that there were four very high concentration "outlier" analyses that were excluded when averaging the results (notes 3, 4 5, and 8). These outliers were 3.59, 585, 31.52, and 28.6 $\mu g/m^3$, respectively. If only the 585 $\mu g/m^3$ value were excluded from the table, rather than all four values, the trends become even more dramatic. The results of including all but the 585 $\mu g/m^3$ value can be seen in Appendix H, which is the modified version of Table 5-3.

Table 5-3 INDUSTRIAL HYGIENE SAMPLING DATA - also see NOTES
(concentrations in micrograms/cubic meter)

CHERRY POINT				TINKER			
Test Date	Hexavalent Chromium Concentration			Test Date	Hexavalent Chromium Concentration		
	Remote Breathing Zone	Near Tank Breathing Zone	In Tank		Remote Breathing Zone	Near Tank Breathing Zone	In Tank
7/11/00	0.041	0.038 (note 3)	1.450	9/12/00 am	0.115	0.014 (note5)	0.201(note 4)
7/12/00	0.033	0.077	1.250	9/12/00 pm	(note 6)	0.022	0.252
9/21/00 am	0.031	0.024	0.023	10/11/00 am	0.007	0.035	0.023
9/21/00 pm	(note 6)	0.043	0.043	10/11/00 pm	(note 6)	0.028	0.033
11/15/00 am	0.056	0.112	2.266	11/8/00 am	0.047	0.014	0.036
11/15/00 pm	(note 6)	(note 6)	2.400	11/8/00 pm	(note 6)	(note 6)	0.078
11/16/00 am	0.042	0.035	0.070	12/6/00	0.028	0.042	0.100
11/16/00 pm	(note 6)	(note 6)	0.120	7/31/01	0.023	0.038	0.053
12/13/00 am	0.014	0.030	0.113	8/1/01 (note 7)	0.050	0.018	4.23(note 8)
12/13/00 pm	(note 6)	0.030	0.075				
3/27/01	0.014	0.186	0.073				
4/17/01	0.028	0.014	0.041				
Averages[9]:							
without FS:	**0.043**	**0.076**	**1.68**		**0.083**	**0.018**	**2.23**
with FS:	**0.026**	**0.060**	**0.067**		**0.026**	**0.031**	**0.060**

NOTES:

1 - Rows with shaded background represent baseline data (i.e., without fume suppressant [FS]).

2 - All values reported below various detection limits were averaged as the detection limit divided by the square root of 2 (i.e., 1.414).
For example: if non-detect was less than 0.020 mic/cu.m. then it was reported as 0.014 (i.e., 0.020/1.414) – see reference 5.

3 - For Cherry Point, a value of 3.59 mic/cu.m. was considered an outlier from the 7/11/00 sampling for "Near Tank Breathing Zone", and was not included in the calculations.

4 - For Tinker, a value of 585 mic/cu.m. was considered an outlier from the 9/12/00 am sampling for "In Tank", and was not included in the calculations.

5 - For Tinker, 9/12/00 am, "Near Tank Breathing Zone", two locations were sampled. One of the locations had a concentration of 31.52 mic/cu.m. This value was considered an outlier, and was not included in calculations.

6 - Only one set of samples was taken during the day, spanning the entire day (i.e., am plus pm). The value shown for "am" represents the entire day.

7 - This baseline sample was taken on Tank 214. All other data were for Tank 222.

8 - For Tinker, 8/1/01, "In Tank", two locations were sampled. One of the locations had a concentration of 28.6 mic/cu.m. This value was considered an outlier, and was not included in the calculations.

9 – To calculate averages, concentrations based on a full-day sampling were given twice the weight as concentrations based on half-day sampling.

For REFERENCE:

1 - Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) is 100 micrograms per cubic meter (mic/cu.m.) as chromic oxide (52 mic/cu.m. as chromium).

2 - **Proposed** OSHA PEL ranges between 0.5 and 5 mic/cu.m.

3 - American Conference on Governmental Industrial Hygienists (ACGIH) Time Weighted Average (TWA) for water-soluble hexavalent chromium compounds is 50 mic/cu.m. as chromium.

4 - National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) for hexavalent chromium compounds is 1 mic/cu.m. as chromium.

5 - Navy Environmental Health Center (NEHC), Industrial Hygiene Field Operations Manual, Chapter 4, Section 8a.(3), page 4-22[9]

5.1.4 Mechanical Quality Data

The following types of testing were performed on samples of steel that were hard chromium electroplated both with and without WA/FS:

- Hydrogen embrittlement,
- Hardness,
- Porosity,
- Adhesion,
- Thickness, and
- Fatigue

Details and results of each testing protocol are discussed and summarized below.

5.1.4.1 *Hydrogen Embrittlement*

The ability of a hard chromium coating to allow for a post-electroplating bake to drive hydrogen from the embrittlement-sensitive steel is critical for implementation. This test is to validate whether the addition of Fumetrol® 140 to the plating solution affects the as-plated, as-baked tensile performance of high-strength steels. Hydrogen embrittlement testing was performed on ASTM F 519 Type 1a.1 notched round bars made from 4340 steel (see Figure 5-3). Bars were chromium plated at all three facilities (Cherry Point, Tinker, and North Island) while using Fumetrol® 140 and from Cherry Point and Tinker with no Fumetrol 140® (controls).

Two types of testing were performed. The first was the standard 200-hour sustained tensile load test per AMS QQ-C-320 as defined in ASTM F 519 (75 percent of ultimate tensile strength [UTS] for 200 hours). The second test was a developmental rising step load (RSL) test that holds the specimen at 75 percent of UTS test for 24 hours, followed by five percent step tensile increases each hour to failure. This new procedure is designed to provide feedback on process quality in about 24 hours versus the standard technique that takes 8 days and is impractical for cost-effective production decisions.

Appendix G details results of the sustained tensile load test completed by Dirats Laboratories as well as results of the rising step load tests completed at NAVAIR Patuxent River. Most importantly, all specimens from all sites and tanks passed the 200-hour sustained tensile load test, indicating that Fumetrol® 140 has no deleterious effect on the embrittlement characteristics of high-strength steels plated with hard chromium. For comparison purposes, all test samples survived the initial 24-hour sustained load of the RSL test (not unexpected due to the success in the 200-hour test) and all samples fractured at an average of between 89.5 and 93.2 percent of UTS. Although there appears to be no statistical difference in performance, the specimens plated from Fumetrol® 140 tanks broke at slightly higher UTS levels. Table 5-4 shows the comparison of the average fracture strengths for each site with and without Fumetrol® 140.

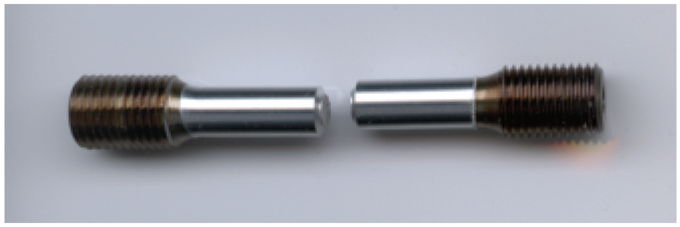


Figure 5-3: Notched Round Bar for Hydrogen Embrittlement Testing

Table 5-4: Average Fracture Strengths (Fracture Percent) for RSL Notched Round Bars

Cherry Point w/o Fumitrol	Cherry Point w/ Fumitrol	North Island w/o Fumitrol	Tinker w/o Fumitrol	Tinker w/ Fumitrol
92.6	92.8	91.0	93.7	93.8
87.8	91.4	93.6	94.3	93.3
91.2	89.0	91.4	91.5	93.8
90.0	90.2	94.2	93.0	94.7
92.3	92.7	91.1	92.3	93.3
90.2	89.5	92.7	93.7	90.2
93.1	90.2	93.2	93.0	93.3
92.2	94.1	93.2	93.5	92.8
74.0	93.2	93.1	90.6	93.8
90.0		90.1		
90.7				
89.5	**91.5**	**92.4**	**92.8**	**93.2**

5.1.4.2 *Hardness*

Per AMS QQ-C-320, the Vickers Hardness test method was planned to be used to determine coating hardness. Due to the availability of hardness testing equipment, the materials test laboratory at NADEP Cherry Point performed the hardness test using their standard technique based on the Rockwell C method. Per Table 5-5, three samples from Cherry Point and Tinker with and without Fumetrol® 140 were chosen at random from a batches of 1” by 4” test coupons. Each of the samples had 10 hardness tests performed on it. The table presents the hardness data using the Rockwell C scale.

Table 5-5: Hardness Tests

Sample	Source	Hardness (Rockwell C)				
		Average of 10 Tests	Average of the Averages	Standard Deviation	Max	Min
1	Cherry Point- no WAFS	63.68		2.86	67.16	57.70
2	Cherry Point- no WAFS	60.01	62.82	3.45	65.23	53.13
3	Cherry Point- no WAFS	64.78		2.12	67.36	60.81
1	Cherry Point- with WAFS	63.19		1.38	64.95	61.04
2	Cherry Point- with WAFS	61.56	63.02	2.86	64.10	54.43
3	Cherry Point- with WAFS	64.31		4.09	67.36	53.13
1	Tinker – no WA/FS	64.12		1.084	65.24	61.93
2	Tinker – no WA/FS	64.74	64.07	1.105	67.00	63.13
3	Tinker – no WA/FS	63.35		2.413	66.41	58.84
1	Tinker – with WA/FS	63.77		0.963	64.95	61.93
2	Tinker – with WA/FS	64.27	63.91	0.932	65.53	62.55
3	Tinker – with WA/FS	63.68		0.873	64.66	61.93

Based on the data, there appears to be no statistical difference between the results with or without Fumetrol® 140. Therefore, the use of Fumetrol® 140 in hard chromium electroplating baths has no detrimental effect on the hardness of the plated part. An additional set of tests was run on three samples from the North Island facility, but only with Fumetrol® 140. The results were similar to the Tinker and Cherry Point data.

5.1.4.3 *Porosity*

The porosity/pitting test detailed in AMS QQ-C-320 provides a relative measure of the quality of the electroplated chromium. Since previous generations of fume suppressants increased the porosity of the electroplated chromium, this is an important test to validate the performance of Fumetrol® 140 relative to previous products and the control tanks.

Initial porosity testing was completed on three samples each from Cherry Point and Tinker with and without Fumetrol® 140, and three samples from North Island. Each sample was a 1” by 4” 4130 steel coupon plated with a 1-mil thick chromium coating. The 1” by 4” coupon size was used instead of the 3” by 10” size detailed by the specification due to processing restraints. For the ferroxyl test, AMS QQ-C-320 allows for 1 pit per 10 square inches of test surface.

Of the test sets, only the Cherry Point set processed from the control tank with no Fumetrol® 140 showed no pits, and passed the specification criteria. The Fumetrol® 140 set from Cherry Point showed small numbers of pits but also appeared to have red rust on the surface of the chromium from processing. This rust may have been deposited from the unplated areas of the test coupons that were in contact with the chromium plating. All coupons from Tinker (with and without Fumetrol® 140) had residual red rust on the chromium surface as well, presumably

leading to the large number of pits seen. For the North Island set, two coupons were pit-free and one had four pits. As a result of the initial tests, there is no evidence that the Fumetrol® 140 changes the porosity of the chromium plating. Because so many coupons did show positive results, it was decided to run another set of tests using thicker coatings and Cherry Point as the coating source.

For this test, the chromium was plated to 3 mils thick for both control and Fumetrol® 140 coatings. The ferroxyl test was completed on five specimens of each coating. Figures 5-4 through 5-6 show the results of the test for the control (i.e., without Fumetrol® 140) and with Fumetrol® 140.

Figure 5-4: Porosity test of hard chromium from tank without Fumetrol® 140 (Cherry Point)

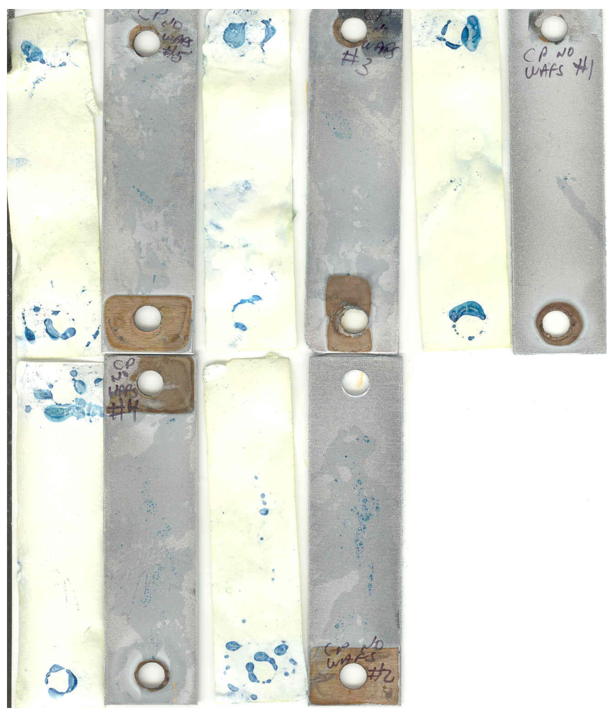


Figure 5-5: Porosity test of hard chromium from tank with Fumetrol® 140 (Cherry Point)

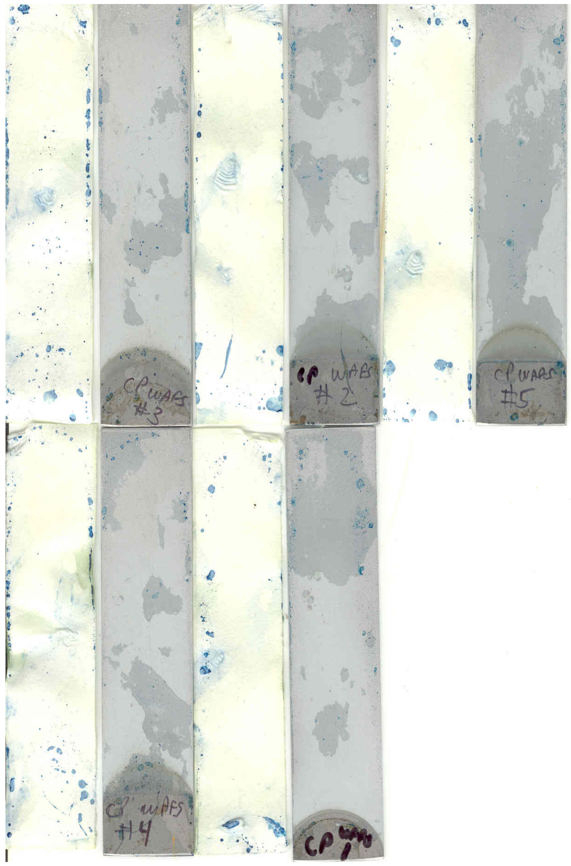
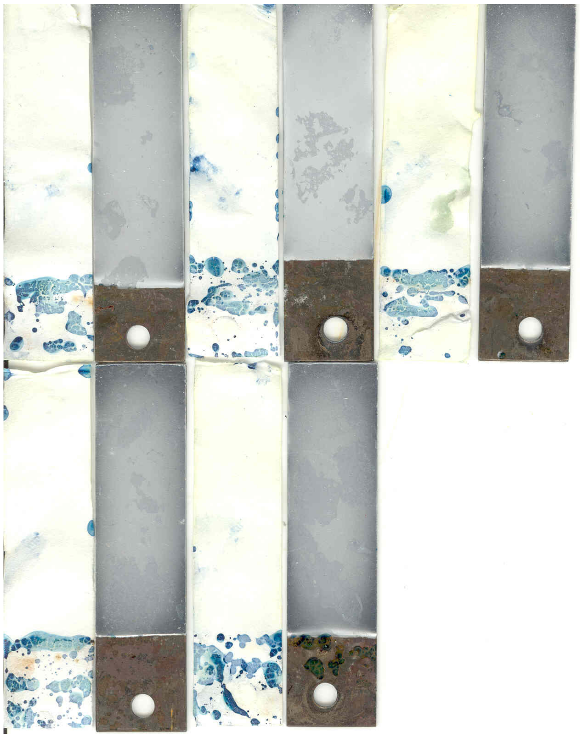


Figure 5-6: Porosity test of hard chromium from tank with Fumetrol® 140 (North Island)



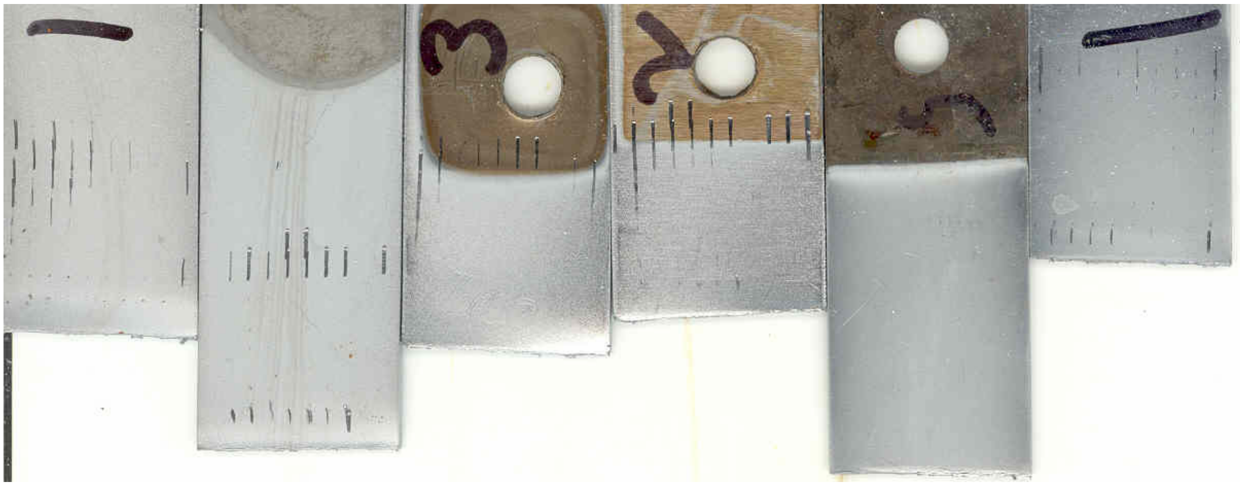
No difference in porosity was noted between the NADEP Cherry Point-plated coatings with and without Fumetrol® 140 in the plating tanks. The overall porosity of the NADEP North Island coatings from a plating tank with Fumetrol® 140 was less than the Cherry Point coatings. As a result, there appears to be no deleterious effect on porosity due to the presence of Fumetrol in the plating tanks.

5.1.4.4 *Adhesion*

A bend-to-break adhesion test was used to evaluate the quality of adhesion of the chromium to the substrate and the potential effect of Fumetrol® 140 on adhesion. Five random samples of the original sets of 1-mil thick coatings from Cherry Point (with and without Fumetrol® 140), Tinker (with and without Fumetrol® 140), and North Island (with Fumetrol® 140) were tested. All samples from Cherry Point and Tinker passed the test in that no loss of adhesion was noted after breaking. The North Island samples showed a small degradation in adhesion that was linked to a quality control problem and resolved.

The test was repeated using five random 3-mil thick coatings from Cherry Point as described in section 5.1.4.3. No samples showed any degradation in adhesion. As a result, Fumetrol® 140 is considered not to have an effect on coating adhesion compared to the control coating. Figure 5-7 shows a series of 3-mil thick test specimens.

Figure 5-7: Adhesion specimens subjected to bend-to-break test



5.1.4.5 *Thickness*

Thickness is not a pass/fail criterion and detailed here to show that the coatings are close to the requested thickness and regular from sample to sample. Table 5-6 details coating thicknesses for samples from each lot of coating for the second round of testing. For each coupon, the thickness shown is an average of three measurements.

Table 5-6: Average Thicknesses of Hard Chromium Coatings (mils)

Coupon	NADEP North Island with Fumetrol	NADEP Cherry Point with Fumetrol	NADEP Cherry Point w/o Fumetrol(control)
1	2.4	3.5	2.6
2	2.7	2.5	2.2
3	2.5	3.5	2.3
4	2.6	3.0	1.9
5	2.5	3.0	0.65
Average	2.5	3.1	1.9

5.1.4.6 *Fatigue*

The potential influence of Fumetrol® 140 on the fatigue characteristics of representative high-strength steels was evaluated by a Limited Equivalence Test as detailed in Appendix F. Also shown in Appendix F are drawings of Fatigue Test Specimens. Three alloys were selected based on their use and importance in DOD on critical components:

- 300M (per AMS 6419),
- Aermet 100 (per AMS 6532), and
- 13-8 (H1000) (per AMS 5629)

Fatigue specimens were designed and machined out of these alloys per ASTM E 466 and ASTM E 606 and supplied by Metcut. Appendix F details the specifications of coupons designed for low and high-cycle axial fatigue tests and the strength levels as manufactured. After receipt from Metcut, the coupons were sent to NADEP Cherry Point for electroplating of hard chromium from a control production tank with no fume suppressant and a test tank with Fumetrol® 140. All test coupons were plated to 0.003 inches (3 mils) of hard chromium per NADEP Cherry Point's normal procedure and subsequently baked for 24 hours at 190°C to remove hydrogen from the specimens. Cherry Point then shipped the plated test specimens back to NAS Patuxent River for fatigue testing.

Specimens were tested in the NAVAIR Materials Mechanical Test Laboratory to the loads and fatigue spectra as detailed in Appendix F. Analysis of the data indicates that the Fumetrol® 140 has no, or a slightly positive, effect on fatigue performance of the test specimens.

5.1.4.7 *Material Effects of Fumetrol 140- Conclusion*

Based on the empirical data from NADEP North Island's use of Fumetrol® 140 for more than five years and the data generated by this project, it appears that Fumetrol® 140, when used in accordance with the testing in this project, has no deleterious effect on the hard chromium plating or steel substrates on which it is electroplated.

5.1.5 Other Data

5.1.5.1 *Perfluorooctyl Sulfonate (PFOS) Releases to the Environment*

According to its Material Safety Data Sheet (MSDS), organic fluorosulfonates (OFS) are the primary active component in the Fumetrol® 140 WA/FS additive used in this study to reduce emissions of chromium mist from the hard chromium electroplating baths that were tested. (The MSDS states that from 1-7 percent of the constituents are OFS.) One type of OFS compounds, perfluorooctane sulfonates (PFOS), is regulated by USEPA under a Significant New Use Rule (SNUR) (see section 7.0). Fumetrol® 140 is added to the electroplating bath at about 0.25 percent by volume, and because no more than 7 percent of the Fumetrol® 140 can be PFOS compounds, there can be no more than about 0.0175 percent of PFOS compounds in the bath. It is unlikely that USEPA will ultimately regulate the use of PFOS compounds at these low levels. The regulation appears to target the primary use of PFOS compounds, which is the treatment of fabrics and paper to provide soil and water resistance.

Nevertheless, during this study one composite stack sample was analyzed for OFS constituents, including PFOS compounds. (The composite consisted of equal parts of the filtered liquid samples from each of the three stack tests performed on 31 July 2001 at the Tinker Air Force Base site.) In addition a sample of the water in the air scrubber effluent holding tank at Tinker was taken to see if the scrubber water blowdown to Tinker's industrial wastewater treatment plant (IWTP) contained PFOS compounds. A sample was also taken of the wastewater influent to the IWTP, which includes the aforementioned scrubber blowdown as well as other industrial wastewaters. Table 5-7 shows the analytical results for these samples. Only two of the 16 analyzed-for organic perfluoride compounds were detected in any of the samples. (The

detection limit for the OFS compounds of concern was 10 micrograms per liter [µg/l], which is the same as 10 parts per billion [ppb]). These were both PFOS compounds. The liquid sample from the stack test contained perfluorooctane sulfonate (one of the PFOS compounds) at a level that equates to 0.0049 milligrams/dry standard cubic meter (mg/dscm) in the air emissions to the scrubber. The other PFOS compound detected was 2-(N-ethylperfluorooctanesulfonamido) ethyl alcohol (PFOSA), at 0.0013 mg/dscm. In addition, perfluorooctane sulfonate was found in the scrubber effluent holding tank at 11 µg/l. No PFOS compounds were detected in the IWTP influent. This is not unexpected, since the effluent sample is highly diluted. A blank sample was also tested, and 11 µg/l of PFOSA were detected. Consequently, one might assume that the PFOSA detected in the liquid sample from the stack test did not really contain any PFOSA.

Table 5-7: Perfluorooctyl Sulfonates (PFOS) Analyses

PFOS Compound	**Stack Test Liquid Sample** (µg/l)	**Equivalent Stack Emissions to Scrubber** (mg/dscm)	**Scrubber Effluent Holding Tank** (µg/l)	**IWTP Influent** (µg/l)	**Blank** (µg/l)
Perfluorooctane Sulfonate	39	0.0049	11	<10	<10
2-(N-ethylperfluorooctane sulfonamido) ethyl alcohol (PFOSA)	10*	0.0013*	<10	<10	11

* Assumed to be 0.0 µg/l since the PFOSA detected in the blank exceeded the PFOSA detected in the actual sample. Similarly, the equivalent stack emission is assumed to be 0.0000 mg/dscm.

The concentrations of the PFOS compounds that were detected are probably suspect for the following two reasons. (1) Only one sample was taken from each of the four sources. (2) The ratio of chromium to PFOS compounds in the electroplating bath is greater than 720:1 (chromium concentration is about 12.6 % and OFS concentration – of which PFOS compounds are only one type of constituent – is less than 0.0175 %). The average concentration of total chromium in the stack emissions to the scrubber from the same tests was 0.0568 mg/dscm. Therefore, the concentration of PFOS compounds should not have exceeded 0.000079 mg/dscm (0.0568/720), as opposed to the 0.0049 suggested in Table 5-7.

Based on the above, it is difficult to draw any comprehensive conclusions from the PFOS testing data except that the concentration of perfluorooctane sulfonate is much less than 0.0049 µg/l in the exhaust gases entering the scrubber; but some PFOS does become entrained in the vapors drawn from the tank surface. No testing was conducted for PFOS after the scrubber.

5.1.5.2 *Concentration of Chromium Plating Bath Constituents*

Five chromium electroplating baths were sampled, two from Cherry Point, two from Tinker, and one from North Island. Two of the five samples were from the baths from which stack and industrial hygiene (IH) samples were taken at Cherry Point and Tinker. Both contained WA/FS. Two of the five samples were from other non-WA/FS chromium electroplating baths at Cherry Point and Tinker. The North Island sample was taken from a chromium electroplating bath containing WA/FS. No definitive conclusions can be drawn from the bath sampling data with respect to the effect of bath contents on: stack sampling, IH sampling, or product quality results. Highlights of the data are presented below.

The sampling data showed that the hexavalent chromium concentrations in each of the five baths ranged from 12.6 – 15.1 percent. (Interestingly, the hexavalent chromium analyses of the five baths *exceeded* the total chromium analyses by 20.0 – 36.6 percent. For instance, for Tank 155 at Cherry Point, the hexavalent chromium concentration was 12.6 percent, and the total chromium concentration was 10.5 percent. This is, of course, a physical impossibility, but this phenomenon is not unusual when analyzing chromium in the percent concentration range [1 percent equals 10,000 mg/l].)

With respect to trace metals, one of the baths sampled had consistently higher trace metal concentrations than the other four baths. (This was Tank 099 at Cherry Point, *not* one of the baths on which stack and IH samples were taken.) Its aluminum concentration was 1,480 mg/l (aluminum ranged from 6.2 - 35.6 mg/l in the other four baths). Its iron concentration was 345 mg/l (iron ranged from 30.4 - 233 mg/l in the other four baths). Its copper concentration was 245 mg/l (copper ranged from 4.75 – 117 mg/l in the other four baths). Its nickel concentration was 140 mg/l (nickel ranged from 1.48 – 8.64 mg/l in the other four baths). Its lead concentration was 57.7 mg/l (lead ranged from 18.0 – 49.8 mg/l in the other four baths). Its zinc concentration was 37.8 mg/l (zinc ranged from 1.78 – 15.9 mg/l in the other four baths). It is theorized that the reason that Tank 009 at Cherry Point has much higher trace components than other baths is because for a long time evaporation makeup for baths at Cherry Point was accomplished using tap water. Conceivably the tap water components would have become concentrated over a long time period.

Suspended solids concentrations in the five baths ranged from 110 – 618 mg/l. The two highest suspended solids values were for Tank 155 at Cherry Point (618 mg/l), and Tank 222 at Tinker (344 mg/l). Both of these baths were the baths that were sampled for stack and IH emissions.

5.2 Technology Comparison

Summarizing section 5.1.2, stack emissions data, it can be stated with great confidence that there is a vast improvement in the emissions of chromium when WA/FS is used (from 20- to 70-fold). However, the emissions performance is still not good enough that emissions will consistently meet USEPA NESHAP standards for chromium emissions from hard chromium electroplating operations without the use of other APCDs (e.g., scrubbers). Nevertheless, significant amounts of chromium that are emitted to exhaust systems when WA/FS is not in use will be saved if the use of WA/FS is implemented. Additional savings will be realized because less chromium will enter and be captured by air scrubber systems, and therefore less chromium will require treatment and disposal as a hazardous waste.

Summarizing section 5.1.3, industrial hygiene (IH) data, it can be stated that occupational exposures to hexavalent chromium, whether or not WA/FS are used, are very low compared to the current OSHA Permitted Exposure Limit (PEL). In general most samples would even comply with the most stringent anticipated OSHA PEL. Regardless, it is also clear that occupational exposures are reduced significantly when WA/FS is used in chromium electroplating baths. Such reduction can only make for a safer working environment for electroplating shop workers.

Summarizing section 5.1.4, material quality, based on the empirical data from NADEP North Island's use of Fumetrol® 140 for more than five years and the data generated by this project, it appears that Fumetrol® 140, when used in accordance with the testing in this project, has no deleterious effect on the hard chromium plating or steel substrates on which it is electroplated.

Table 5–8: SUMMARY OF RESULTS - Cherry Point, NC, Tank 155 Stack Test, 11/12 July 2000						
Run Number	1*	2	3	4	5	6
Field Data Inputs:						
Barrier in Place (Y or N)	N	N	N	Y	Y	Y
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	N	N	N	N	N	N
Bath Surface Area (ft^2)	21.5	21.5	21.5	21.5	21.5	21.5
Bath Freeboard (inches)	8.0	8.0	8.0	8.0	8.0	8.0
Exhaust Intake Area (ft^2)	3.22	3.22	3.22	3.22	3.22	3.22
Barometric Pressure (in.Hg) - P_b	29.86	29.86	29.86	29.94	29.94	29.94
Stack Diameter (ft.) - D_s	1.667	1.667	1.667	1.667	1.667	1.667
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.48	0.52	0.54	0.47	0.53	0.50
$\Delta P^{0.5}$	0.67	0.72	0.72	0.68	0.71	0.69
Stack Temperature ($^\circ$F) - T_s	88	91	92	84	86	88
Stack Static Pressure (in.H_2O) - P_s	-2.4	-2.8	-2.8	-2.5	-2.5	-3.0
Absolute Pressure (in.Hg) - P_a	29.68	29.65	29.65	29.76	29.76	29.72
Dry Gas Meter Volume Sampled (ft^3) - V_m	88.36	55.49	55.8	52.75	56.22	53.85
Average Dry Gas Meter Temperature ($^\circ$F) - T_m	92	93	95	88	90	91.5
Dry Gas Meter Cal. Factor (dimensionless)	1.0089	1.0089	1.0089	1.0089	1.0089	1.0089
Orifice $\Delta H_@$ (in.H_2O)	1.7260	1.7260	1.7260	1.7260	1.7260	1.7260
Average Orifice Diff. Pressure (in.H_2O) - ΔH	1.75	0.65	0.68	0.57	0.65	0.60
Water Collected (gm) - V_{lc}	106.0	29.6	28.5	25.5	28.1	25.8
Sampling Time (min.) - θ	120	120	120	120	120	121.5
Nozzle Diameter (inches) – D_n	0.250	0.1875	0.1875	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	370	430	440	480	505	490

Table 5–8: Cherry Point – 11/12 July – (Continued)

Flow Results:						
Average Stack Velocity (ft/sec) - V_s	38.80	41.59	41.62	38.94	40.74	39.68
Dry Standard Meter Volume (dscf) - V_{dscf}	85.43	53.33	53.52	51.36	54.55	52.11
Moisture in Sample (as a gas, ft^3) – M	4.98	1.39	1.34	1.20	1.32	1.21
Moisture in Sample (%) - M_p	5.51	2.54	2.44	2.28	2.36	2.27
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.39	28.72	28.73	28.75	28.74	28.75
Stack Area (ft^2) – A	2.18	2.18	2.18	2.18	2.18	2.18
Actual Stack Flow Rate (acfm) - Q_a	5,080	5,440	5,450	5,100	5,330	5,190
Standard Stack Flow Rate (scfm) - Q_s	4,860	5,170	5,170	4,920	5,130	4,970
Dry Standard Stack Flow (dscfm) - Q_d	4,590	5,040	5,040	4,810	5,010	4,860
Isokinetic Rate (% of Isokinetic) - I	99.20	100.21	100.57	101.14	103.14	100.29
Laboratory Analysis:						
Total Chromium Concentration (mg/l) - C_t	0.46	23.9	2.94	12.3	2.81	4.70
Hex.Chromium Concentration (mg/l) - C_h	0.31	22.2	2.54	9.47	2.79	4.12
Percent Hexavalent Chromium (%)	67.4	92.9	86.4	77.0	99.3	87.7
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.170	10.28	1.29	5.90	1.42	2.30
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.115	9.55	1.12	4.55	1.41	2.02

Table 5–8: Cherry Point - 11/12 July - (Continued)

Operational Parameters:						
Volts – E	not avail.	not avail.	not avail.	6.08	6.07	6.07
Average Amperes – AM	not avail.	not avail.	not avail.	1,341	1,476	1,466
Ampere-Hours (Amp-hr) - AH	not avail.	1,891	525	3,055	3,378	3,138
Hours Between AH Meter Readings - θ_{AH}	not avail.	1.6	2.2	2.4	2.4	2.1
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x 2/θ_{AH})	not avail.	2,363	477	2,546	2,815	2,989
Emission Results:						
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.00199	0.193	0.0242	0.115	0.0260	0.0442
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.00134	0.179	0.0209	0.0885	0.0258	0.0387
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.0703	6.804	0.853	4.06	0.919	1.56
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.0454	6.32	0.737	3.13	0.912	1.37
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	not avail.	49.3	30.6	26.1	5.55	8.73
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	not avail.	45.8	26.5	20.1	5.51	7.65

* For run number 1 there was no electroplating load in the plating bath (i.e., nothing was being electroplated). Consequently, the emissions data from only runs 2 and 3 were used to determine average emissions results for 11 July 2000.

Table 5–9: SUMMARY OF RESULTS - Cherry Point, NC, Tank 155 Stack Test, 21 Sep 2000			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 33	Y 33	Y 33
Bath Surface Area (ft^2)	21.5	21.5	21.5
Bath Freeboard (inches)	8.0	8.0	8.0
Exhaust Intake Area (ft^2)	3.22	3.22	3.22
Barometric Pressure (in.Hg) - P_b	29.94	29.94	29.94
Stack Diameter (ft.) - D_s	1.667	1.667	1.667
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.94	0.96	0.94
$\Delta P^{0.5}$	0..96	0.97	0.96
Stack Temperature (°F) - T_s	87	90	90
Stack Static Pressure (in.H_2O) - P_s	-2.7	-2.7	-2.7
Absolute Pressure (in.Hg) - P_a	29.74	29.74	29.74
Dry Gas Meter Volume Sampled (ft^3) - V_m	73.984	74.253	74.771
Average Dry Gas Meter Temperature (°F) - T_m	92	98	99
Dry Gas Meter Cal. Factor (dimensionless)	0.9956	0.9956	0.9956
Orifice $\Delta H_{@}$ (in.H_2O)	1.8475	1.8475	1.8475
Average Orifice Diff. Pressure (in.H_2O) - ΔH	1.13	1.24	1.25
Water Collected (gm) - V_{lc}	41.1	38.0	42.2
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	389	447	451

Table 5–9: Cherry Point - 21 Sep - (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	55.18	55.89	55.34
Dry Standard Meter Volume (dscf) - V_{dscf}	70.67	70.18	70.55
Moisture in Sample (as a gas, ft^3) - M	1.93	1.79	1.98
Moisture in Sample (%) - M_p	2.66	2.48	2.74
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.71	28.73	28.70
Stack Area (ft^2) – A	2.18	2.18	2.18
Actual Stack Flow Rate (acfm) - Q_a	7,220	7,320	7,240
Standard Stack Flow Rate (scfm) - Q_s	6,930	6,980	6,910
Dry Standard Stack Flow (dscfm) - Q_d	6,750	6,810	6,730
Isokinetic Rate (% of Isokinetic) - I	99.18	97.60	99.34
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.248	0.163	0.105
Hex.Chromium Concentration (mg/l) - C_h	0.215	0.133	0.0959
Percent Hexavalent Chromium (%)	86.7	81.6	91.3
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.0965	0.729	0.474
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0836	0.0595	0.0433

Table 5-9: Cherry Point - 21 Sep - (Continued)

Operational Parameters:			
Volts – E	5.0	5.0	5.0
Average Amperes – AM	1,245	1,245	1,225
Ampere-Hours (Amp-hr) - AH	3,268	3,268	2,589
Hours Between AH Meter Readings - θ_{AH}	2.1	2.1	2.2
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	3,112	3,112	2,354
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.00137	0.00104	0.000671
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.00118	0.000847	0.000613
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.0482	0.0367	0.0237
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.0418	0.0299	0.0216
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.355	0.273	0.230
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.308	0.222	0.210

Table 5-10: SUMMARY OF RESULTS - Cherry Point, NC, Tank 155 Stack Test, 15/16 Nov 2000						
Run Number	1	2	3	4	5	6
Field Data Inputs:						
Barrier in Place (Y or N)	N	N	N	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	N	N	N	Y 23.1	Y 23.1	Y 23.1
Bath Surface Area (ft^2)	21.5	21.5	21.5	21.5	21.5	21.5
Bath Freeboard (inches)	8.0	8.0	8.0	8.0	8.0	8.0
Exhaust Intake Area (ft^2)	3.22	3.22	3.22	3.22	3.22	3.22
Barometric Pressure (in.Hg) - P_b	30.03	30.03	30.03	30.13	30.13	30.13
Stack Diameter (ft.) - D_s	1.667	1.667	1.667	1.667	1.667	1.667
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.76	0.71	0.59	0.90	0.95	0.87
$\Delta P^{0.5}$	0.86	0.83	0.76	0.93	0.96	0.92
Stack Temperature (°F) - T_s	62.0	64.1	63.8	60.9	66.7	67.3
Stack Static Pressure (in.H_2O) - P_s	-2.5	-2.5	-2.5	-2.7	-2.7	-2.7
Absolute Pressure (in.Hg) - P_a	29.85	29.85	29.85	29.93	29.93	29.93
Dry Gas Meter Volume Sampled (ft^3) - V_m	53.759	53.644	48.637	59.762	62.412	59.827
Average Dry Gas Meter Temperature (°F) - T_m	67.2	68.6	69.7	66.9	72.8	73.5
Dry Gas Meter Cal. Factor (dimensionless)	1.0043	1.0043	1.0043	1.0043	1.0043	1.0043
Orifice $\Delta H_@$ (in.H_2O)	1.6696	1.6696	1.6696	1.6696	1.6696	1.6696
Average Orifice Diff. Pressure (in.H_2O) - ΔH	0.91	0.86	0.72	1.10	1.15	1.07
Water Collected (gm) - V_{lc}	7.2	7.0	7.0	10.8	15.4	12.8
Sampling Time (min.) - θ	120	120	120	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	379	379	360	372	396	343

Table 5-10: Cherry Point – 15/16 Nov - (Continued)

Flow Results:						
Average Stack Velocity (ft/sec) - V_s	48.02	46.43	42.51	51.82	53.82	51.59
Dry Standard Meter Volume (dscf) - V_{dscf}	54.37	54.10	48.94	60.71	62.70	60.02
Moisture in Sample (as a gas, ft^3) – M	0.338	0.329	0.329	0.508	0.724	0.602
Moisture in Sample (%) - M_p	0.619	0.604	0.668	0.829	1.14	0.992
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.93	28.93	28.93	28.91	28.87	28.90
Stack Area (ft^2) – A	2.18	2.18	2.18	2.18	2.18	2.18
Actual Stack Flow Rate (acfm) - Q_a	6,290	6,080	5,560	6,780	7,050	6,750
Standard Stack Flow Rate (scfm) - Q_s	6,340	6,110	5,600	6,880	7,070	6,770
Dry Standard Stack Flow (dscfm) - Q_d	6,300	6,070	5,560	6,820	6,990	6,700
Isokinetic Rate (% of Isokinetic) - I*	81.7	84.4	83.4	84.3	85.0	84.8
Laboratory Analysis:						
Total Chromium Concentration (mg/l) - C_t	6.37	5.30	4.65	0.199	0.212	0.336
Hex.Chromium Concentration (mg/l) - C_h	6.04	5.25	4.84	0.206	0.216	0.336
Percent Hexavalent Chromium (%)	94.8	99.1	104.1	103.5	101.9	100.0
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	2.41	2.01	1.67	0.0740	0.0840	0.115
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	2.29	1.99	1.74	0.0766	0.0855	0.115

* Isokinicity was uniformly low due to a foreign object that had lodged in the critical orifice of the stack sampling apparatus.

Table 5-10: Cherry Point – 15/16 Nov - (Continued)

Operational Parameters:						
Volts – E	4.84	4.82	4.81	4.82	4.82	4.81
Average Amperes – AM	1,260	1,296	1,278	1,274	1,274	1,324
Ampere-Hours (Amp-hr) - AH	2,956	2,928	3,003	2,760	2,755	2,859
Hours Between AH Meter Readings - θ_{AH}	2.15	2.3	2.3	2.15	2.2	2.2
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	2,750	2,546	2,611	2,567	2,505	2,599
Emission Results:						
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.0444	0.0371	0.0342	0.00122	0.00134	0.00192
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.0421	0.0368	0.0356	0.00126	0.00136	0.00192
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	1.57	1.31	1.21	0.0431	0.0473	0.0678
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	1.49	1.30	1.26	0.0446	0.0482	0.0678
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	12.2	10.6	8.74	0.389	0.448	0.594
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	11.58	10.53	9.10	0.403	0.457	0.594

Table 5-11: SUMMARY OF RESULTS - Cherry Point, NC, Tank 155 Stack Test, 13 DEC 00			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 23.4	Y 23.4	Y 23.4
Bath Surface Area (ft^2)	21.5	21.5	21.5
Bath Freeboard (inches)	8.0	8.0	8.0
Exhaust Intake Area (ft^2)	3.22	3.22	3.22
Barometric Pressure (in.Hg) - P_b	30.50	30.50	30.50
Stack Diameter (ft.) - D_s	1.667	1.667	1.667
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.65	0.87	0.73
$\Delta P^{0.5}$	0.79	0.92	0.83
Stack Temperature (°F) - T_s	63.6	67.5	68.1
Stack Static Pressure (in.H_2O) - P_s	-1.6	-2.1	-2.1
Absolute Pressure (in.Hg) - P_a	30.38	30.35	30.35
Dry Gas Meter Volume Sampled (ft^3) - V_m	58.532	67.784	62.900
Average Dry Gas Meter Temperature (°F) - T_m	69.2	73.9	75.1
Dry Gas Meter Cal. Factor (dimensionless)	1.0086	1.0086	1.0086
Orifice $\Delta H_@$ (in.H_2O)	1.8199	1.8199	1.8199
Average Orifice Diff. Pressure (in.H_2O) - ΔH	0.85	1.16	0.98
Water Collected (gm) - V_{lc}	2.3	5.7	8.2
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	319	356	364

Table 5-11: Cherry Point – 13 December - (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	43.75	51.19	46.23
Dry Standard Meter Volume (dscf) - V_{dscf}	60.14	69.09	63.94
Moisture in Sample (as a gas, ft^3) - M	0.108	0.268	0.385
Moisture in Sample (%) - M_p	0.179	0.386	0.599
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	28.71	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.98	28.96	28.93
Stack Area (ft^2) – A	2.18	2.18	2.18
Actual Stack Flow Rate (acfm) - Q_a	5,730	6,700	6,050
Standard Stack Flow Rate (scfm) - Q_s	5,870	6,800	6,140
Dry Standard Stack Flow (dscfm) - Q_d	5,850	6,780	6,100
Isokinetic Rate (% of Isokinetic) - I	97.27	96.53	99.25
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.103	0.159	0.121
Hex.Chromium Concentration (mg/l) - C_h	0.0906	0.150	0.116
Percent Hexavalent Chromium (%)	88.0	94.3	95.9
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.0329	0.0566	0.0440
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0289	0.0534	0.0422

Table 5-11: Cherry Point – 13 December - (Continued)

Operational Parameters:			
Volts – E	6.03	6.01	6.01
Average Amperes – AM	848	872	886
Ampere-Hours (Amp-hr) - AH	1,836	1,888	1,789
Hours Between AH Meter Readings - θ_{AH}	2.15	2.2	2.1
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	1,708	1,716	1,704
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.000546	0.000819	0.000689
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.000481	0.000773	0.000660
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.0193	0.0289	0.0243
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.0170	0.0273	0.0233
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.225	0.388	0.296
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.198	0.366	0.284

Table 5-12: SUMMARY OF RESULTS - Cherry Point, NC, Tank 155 Stack Test, 27 MAR 01			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 27	Y 27	Y 27
Bath Surface Area (ft^2)	21.5	21.5	21.5
Bath Freeboard (inches)	8.0	8.0	8.0
Exhaust Intake Area (ft^2)	3.22	3.22	3.22
Barometric Pressure (in.Hg) - P_b	30.20	30.20	30.20
Stack Diameter (ft.) - D_s	1.667	1.667	1.667
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	1.12	1.18	1.16
$\Delta P^{0.5}$	1.05	1.07	1.06
Stack Temperature ($^\circ$F) - T_s	61.2	64.9	67.8
Stack Static Pressure (in.H_2O) - P_s	-3.0	-3.0	-3.0
Absolute Pressure (in.Hg) - P_a	29.98	29.98	29.98
Dry Gas Meter Volume Sampled (ft^3) - V_m	75.823	82.914	82.402
Average Dry Gas Meter Temperature ($^\circ$F) - T_m	63.2	66.1	63.0
Dry Gas Meter Cal. Factor (dimensionless)	0.9922	0.9922	0.9922
Orifice $\Delta H_@$ (in.H_2O)	1.7101	1.7101	1.7101
Average Orifice Diff. Pressure (in.H_2O) - ΔH	1.38	1.49	1.46
Water Collected (gm) - V_{lc}	0.0	0.4	0.6
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	323	393	413

Table 5-12: Cherry Point – 27 March – (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	58.38	59.71	59.31
Dry Standard Meter Volume (dscf) - V_{dscf}	76.859	83.606	83.576
Moisture in Sample (as a gas, ft^3) - M	0.000	0.019	0.028
Moisture in Sample (%) - M_p	0.000	0.022	0.034
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	29.00	29.00	29.00
Stack Area (ft^2) – A	2.18	2.18	2.18
Actual Stack Flow Rate (acfm) - Q_a	7,640	7,820	7,760
Standard Stack Flow Rate (scfm) - Q_s	7,760	7,880	7,780
Dry Standard Stack Flow (dscfm) - Q_d	7,760	7,880	7,780
Isokinetic Rate (% of Isokinetic) - I	93.80	100.50	101.70
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.240	0.325	0.200
Hex. Chromium Concentration (mg/l) - C_h	0.211	0.321	0.158
Percent Hexavalent Chromium (%)	87.9	98.8	79.0
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt0}	0.0775	0.1277	0.0826
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0682	0.126	0.0653

Table 5-12: Cherry Point – 27 March – (Continued)

Operational Parameters:			
Volts – E	5.01	5.0	5.0
Average Amperes – AM	1,479	1,492	1,498
Ampere-Hours (Amp-hr) - AH	3,325	3,295	3,179
Hours between AH Meter Readings - θ_{AH}	2.2	2.25	2.2
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	3,023	2,929	2,890
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.00101	0.00153	0.000988
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.000887	0.00151	0.000781
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.0356	0.0539	0.0349
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.0313	0.0533	0.0276
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.311	0.493	0.319
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.273	0.487	0.252

Table 5-13: SUMMARY OF RESULTS - Cherry Point, NC, Tank 155 Stack Test, 17 April 01			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 27	Y 27	Y 27
Bath Surface Area (ft^2)	21.5	21.5	21.5
Bath Freeboard (inches)	8.0	8.0	8.0
Exhaust Intake Area (ft^2)	3.22	3.22	3.22
Barometric Pressure (in.Hg) - P_b	29.80	29.80	29.80
Stack Diameter (ft.) - D_s	1.667	1.667	1.667
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	1.02	1.07	1.12
$\Delta P^{0.5}$	0.99	1.02	1.05
Stack Temperature ($^\circ$F) - T_s	72.0	72.0	70.2
Stack Static Pressure (in.H_2O) - P_s	-2.8	-2.8	-3.2
Absolute Pressure (in.Hg) - P_a	29.59	29.59	29.56
Dry Gas Meter Volume Sampled (ft^3) - V_m	75.745	81.579	83.573
Average Dry Gas Meter Temperature ($^\circ$F) - T_m	79.6	80.9	78.9
Dry Gas Meter Cal. Factor (dimensionless)	0.9922	0.9922	0.9922
Orifice $\Delta H_@$ (in.H_2O)	1.7101	1.7101	1.7101
Average Orifice Diff. Pressure (in.H_2O) - ΔH	1.26	1.35	1.42
Water Collected (gm) - V_{lc}	8.8	10.4	11.3
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	369	369	370

Table 5-13: Cherry Point – 17 April – (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	56.03	57.74	59.37
Dry Standard Meter Volume (dscf) - V_{dscf}	73.442	78.926	81.169
Moisture in Sample (as a gas, ft^3) - M	0.414	0.489	0.531
Moisture in Sample (%) - M_p	0.560	0.616	0.650
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	29.94	29.93	29.93
Stack Area (ft^2) – A	2.18	2.18	2.18
Actual Stack Flow Rate (acfm) - Q_a	7,340	7,560	7,770
Standard Stack Flow Rate (scfm) - Q_s	7,200	7,420	7,650
Dry Standard Stack Flow (dscfm) - Q_d	7,160	7,380	7,600
Isokinetic Rate (% of Isokinetic) - I	97.11	101.34	101.15
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.123	0.0990	0.130
Hex. Chromium Concentration (mg/l) - C_h	0.121	0.0925	0.127
Percent Hexavalent Chromium (%)	98.4	93.4	97.7
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.0454	0.0365	0.0481
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0446	0.0341	0.0470

Table 5-13: Cherry Point – 17 April – (Continued)

Operational Parameters:			
Volts – E	4.99	4.98	4.98
Average Amperes – AM	939	979	990
Ampere-Hours (Amp-hr) - AH	2,105	1,991	2,011
Hours between AH Meter Readings - θ_{AH}	2.3	2.1	2.1
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	1,830	1,896	1,915
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.000618	0.000463	0.000593
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.000608	0.000432	0.000579
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.0218	0.0163	0.0209
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.0215	0.0153	0.0204
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.290	0.216	0.282
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.285	0.202	0.276

Table 5-14: SUMMARY OF RESULTS - Tinker AFB, Tank 222, 12 Sep 00			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	N	N	N
Bath Surface Area (ft^2)	26.8	26.8	26.8
Bath Freeboard (inches)	7.5	7.5	7.5
Exhaust Intake Area (ft^2)	2.65	2.65	2.65
Barometric Pressure (in.Hg) - P_b	29.87	29.87	29.92
Stack Diameter (ft.) - D_s	1.83	1.83	1.83
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.77	0.75	0.79
$\Delta P^{0.5}$	0.87	0.86	0.88
Stack Temperature (°F) - T_s	78.6	89.2	93.9
Stack Static Pressure (in.H_2O) - P_s	-2.3	-2.3	-2.3
Absolute Pressure (in.Hg) - P_a	29.70	29.70	29.75
Dry Gas Meter Volume Sampled (ft^3) - V_m	69.104	68.361	70.546
Average Dry Gas Meter Temperature (°F) - T_m	85.6	97.5	103.9
Dry Gas Meter Cal. Factor (dimensionless)	0.9956	0.9956	0.9956
Orifice $\Delta H_{@}$ (in.H_2O)	1.8475	1.8475	1.8475
Average Orifice Diff. Pressure (in.H_2O) - ΔH	1.00	0.953	1.05
Water Collected (gm) - V_{lc}	22	32	54
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	475	475	470

Table 5-14: Tinker – 12 September - (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	49.55	49.53	50.99
Dry Standard Meter Volume (dscf) - V_{dscf}	66.61	64.48	65.91
Moisture in Sample (as a gas, ft^3) - M	1.03	1.50	2.54
Moisture in Sample (%) - M_p	1.53	2.28	3.71
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.83	28.75	28.59
Stack Area (ft^2) – A	2.64	2.64	2.64
Actual Stack Flow Rate (acfm) - Q_a	7,850	7,850	8,080
Standard Stack Flow Rate (scfm) - Q_s	7,640	7,490	7,660
Dry Standard Stack Flow (dscfm) - Q_d	7,520	7,320	7,370
Isokinetic Rate (% of Isokinetic) - I	101.5	101.0	102.4
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	2.56	1.28	1.76
Hex.Chromium Concentration (mg/l) - C_h	2.05	1.10	1.38
Percent Hexavalent Chromium (%)	80.1	85.9	78.4
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	1.22	0.608	0.827
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.974	0.523	0.649

Table 5-14: Tinker – 12 September - (Continued)

Operational Parameters:			
Volts (average of 3 bath sections) - E	1.77	3.89	3.76
Average Amperes (avg. of 3 bath sections) - AM	131	118	120
Ampere-Hours (Amp-hr) (total of 3 bath sections) - AH	3,174	25,516	18,054
Hours Between AH Meter Readings - θ_{AH}	n/a	n/a	n/a
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	n/a	n/a	n/a
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.0183	0.00943	0.0126
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.0146	0.00810	0.00984
Total Chromium Exhaust Conc. (Mg/dscm) - C_{st}	0.645	0.333	0.443
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.516	0.286	0.347
Total Chromium Emitted/Amp-Hr (mg/Am-hr) - CAH_t	5.19	0.324	0.615
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	4.16	0.279	0.482

Table 5-15: SUMMARY OF RESULTS - Tinker AFB, Tank 222, 11 Oct 00			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 34	Y 34	Y 34
Bath Surface Area (ft^2)	26.8	26.8	26.8
Bath Freeboard (inches)	7.5	7.5	7.5
Exhaust Intake Area (ft^2)	2.65	2.65	2.65
Barometric Pressure (in.Hg) - P_b	30.22	30.22	30.22
Stack Diameter (ft.) - D_s	1.83	1.83	1.83
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.76	0.78	0.80
$\Delta P^{0.5}$	0.87	0.87	0.89
Stack Temperature (°F) - T_s	65.6	70.6	76.0
Stack Static Pressure (in.H_2O) - P_s	-2.3	-2.3	-2.3
Absolute Pressure (in.Hg) - P_a	30.05	30.05	30.05
Dry Gas Meter Volume Sampled (ft^3) - V_m	65.995	67.006	69.390
Average Dry Gas Meter Temperature (°F) - T_m	76.2	84.4	92.9
Dry Gas Meter Cal. Factor (dimensionless)	1.0092	1.0092	1.0092
Orifice $\Delta H_@$ (in.H_2O)	1.7398	1.7398	1.7398
Average Orifice Diff. Pressure (in.H_2O) - ΔH	0.95	1.00	1.04
Water Collected (gm) - V_{lc}	4.3	8.6	10.8
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	366	380	341

Table 5-15: Tinker – 11 October - (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	48.55	48.81	50.19
Dry Standard Meter Volume (dscf) - V_{dscf}	66.37	66.38	67.69
Moisture in Sample (as a gas, ft^3) - M	0.202	0.404	0.508
Moisture in Sample (%) - M_p	0.304	0.605	0.744
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.97	28.93	28.92
Stack Area (ft^2) – A	2.64	2.64	2.64
Actual Stack Flow Rate (acfm) - Q_a	7,690	7,730	7,950
Standard Stack Flow Rate (scfm) - Q_s	7,760	7,730	7,870
Dry Standard Stack Flow (dscfm) - Q_d	7,740	7,680	7,810
Isokinetic Rate (% of Isokinetic) - I	98.30	99.02	99.32
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.0457	0.0620	0.0625
Hex.Chromium Concentration (mg/l) - C_h	0.0420	0.0516	0.0351
Percent Hexavalent Chromium (%)	91.9	83.2	56.2
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.0167	0.0236	0.0213
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0154	0.0196	0.0120

Table 5-15: Tinker – 11 October - (Continued)

Operational Parameters:			
Volts (average of 3 bath sections) - E	4.99	4.84	4.76
Average Amperes (avg. of 3 bath sections) - AM	150	151	154
Ampere-Hours (Amp-hr) (total of 3 bath sections) - AH	9,392	9,903	10,062
Hours Between AH Meter Readings - θ_{AH}	n/a	n/a	n/a
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	n/a	n/a	n/a
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.000252	0.000355	0.000315
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.000232	0.000295	0.000177
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.00890	0.0125	0.0111
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.00818	0.0104	0.00624
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.0249	0.0330	0.0293
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.0229	0.0275	0.0165

Table 5-16: SUMMARY OF RESULTS - Tinker AFB, Tank 222, 8 Nov 00			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 27	Y 27	Y 27
Bath Surface Area (ft^2)	26.8	26.8	26.8
Bath Freeboard (inches)	7.5	7.5	7.5
Exhaust Intake Area (ft^2)	2.65	2.65	2.65
Barometric Pressure (in.Hg) - P_b	29.99	29.99	29.99
Stack Diameter (ft.) - D_s	1.83	1.83	1.83
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.70	0.74	0.72
$\Delta P^{0.5}$	0.83	0.85	0.84
Stack Temperature ($^\circ$F) - T_s	58.1	58.1	56.4
Stack Static Pressure (in.H_2O) - P_s	-2.3	-2.3	-2.3
Absolute Pressure (in.Hg) - P_a	29.82	29.82	29.82
Dry Gas Meter Volume Sampled (ft^3) - V_m	61.692	66.191	65.511
Average Dry Gas Meter Temperature ($^\circ$F) - T_m	66.6	67.3	66.4
Dry Gas Meter Cal. Factor (dimensionless)	1.0043	1.0043	1.0043
Orifice $\Delta H_@$ (in.H_2O)	1.6696	1.6696	1.6696
Average Orifice Diff. Pressure (in.H_2O) - ΔH	0.96	0.92	0.90
Water Collected (gm) - V_{lc}	6.8	8.1	10.3
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	387	348	369

Table 5-16: Tinker – 8 November - (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	46.18	47.30	46.68
Dry Standard Meter Volume (dscf) - V_{dscf}	62.374	66.843	66.267
Moisture in Sample (as a gas, ft^3) - M	0.320	0.381	0.484
Moisture in Sample (%) - M_p	0.510	0.566	0.725
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.94	28.94	28.92
Stack Area (ft^2) – A	2.64	2.64	2.64
Actual Stack Flow Rate (acfm) - Q_a	7,310	7,490	7,390
Standard Stack Flow Rate (scfm) - Q_s	7,430	7,610	7,540
Dry Standard Stack Flow (dscfm) - Q_d	7,390	7,570	7,480
Isokinetic Rate (% of Isokinetic) - I	96.67	101.21	101.49
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.0409	0.0349	0.0152
Hex.Chromium Concentration (mg/l) - C_h	0.0397	0.0389	0.0150
Percent Hexavalent Chromium (%)	97.1	111.5	98.7
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.0158	0.0121	0.00561
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0154	0.0135	0.00554

Table 5-16: Tinker – 8 November - (Continued)

Operational Parameters:			
Volts (average of 3 bath sections) - E	3.81	3.99	4.00
Average Amperes (avg. of 3 bath sections) - AM	191	211	211
Ampere-Hours (Amp-hr) (total of 3 bath sections) - AH	24,360	24,395	24,423
Hours Between AH Meter Readings - θ_{AH}	n/a	n/a	n/a
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	n/a	n/a	n/a
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.000254	0.000182	0.0000846
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.000246	0.000203	0.0000835
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.00896	0.00642	0.00299
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.00870	0.00715	0.00295
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.00924	0.00676	0.00311
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.00897	0.00754	0.00307

Table 5-17: SUMMARY OF RESULTS - Tinker AFB, Tank 222, 6 Dec 00			
Run Number	1	2	3
Field Data Inputs:			
Barrier in Place (Y or N)	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surface Tension (dynes/cm)	Y 30.5	Y 30.5	Y 30.5
Bath Surface Area (ft^2)	26.8	26.8	26.8
Bath Freeboard (inches)	7.5	7.5	7.5
Exhaust Intake Area (ft^2)	2.65	2.65	2.65
Barometric Pressure (in.Hg) - P_b	30.14	30.14	30.14
Stack Diameter (ft.) - D_s	1.83	1.83	1.83
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.72	0.70	0.68
$\Delta P^{0.5}$	0.84	0.84	0.81
Stack Temperature (°F) - T_s	78.8	77.7	79.3
Stack Static Pressure (in.H_2O) - P_s	-2.5	-2.5	-2.5
Absolute Pressure (in.Hg) - P_a	29.96	29.96	29.96
Dry Gas Meter Volume Sampled (ft^3) - V_m	66.347	65.225	63.347
Average Dry Gas Meter Temperature (°F) - T_m	87.6	87.6	88.3
Dry Gas Meter Cal. Factor (dimensionless)	1.0086	1.0086	1.0086
Orifice $\Delta H_@$ (in.H_2O)	1.8199	1.8199	1.8199
Average Orifice Diff. Pressure (in.H_2O) - ΔH	0.96	0.95	0.92
Water Collected (gm) - V_{lc}	3.5	5.6	6.4
Sampling Time (min.) - θ	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.1875
Total Impinger + Wash Volume (ml) - V_{tot}	335	378	409

Table 5-17: Tinker – 6 December - (Continued)

Flow Results:			
Average Stack Velocity (ft/sec) - V_s	47.53	47.49	45.87
Dry Standard Meter Volume (dscf) - V_{dscf}	65.123	64.020	62.093
Moisture in Sample (as a gas, ft^3) - M	0.165	0.263	0.301
Moisture in Sample (%) - M_p	0.252	0.409	0.482
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.97	28.95	28.95
Stack Area (ft^2) – A	2.64	2.64	2.64
Actual Stack Flow Rate (acfm) - Q_a	7,530	7,520	7,270
Standard Stack Flow Rate (scfm) - Q_s	7,390	7,400	7,120
Dry Standard Stack Flow (dscfm) - Q_d	7,370	7,370	7,090
Isokinetic Rate (% of Isokinetic) - I	101.3	99.6	100.4
Laboratory Analysis:			
Total Chromium Concentration (mg/l) - C_t	0.132	0.103	0.0539
Hex.Chromium Concentration (mg/l) - C_h	0.129	0.0892	0.0457
Percent Hexavalent Chromium (%)	97.7	86.6	84.8
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.0442	0.0389	0.0220
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.0432	0.0337	0.0187

Table 5-17: Tinker – 6 December - (Continued)

Operational Parameters:			
Volts (average of 3 bath sections) - E	4.93	4.90	4.87
Average Amperes (avg. of 3 bath sections) - AM	120	119	119
Ampere-Hours (Amp-hr) (total of 3 bath sections) - AH	19,821	12,682	19,676
Hours Between AH Meter Readings - θ_{AH}	2.0	0.625	2.0
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	19,821	20,291	19,676
Emission Results:			
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.000679	0.000608	0.000355
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.000664	0.000527	0.000301
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.0240	0.0215	0.0125
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.0234	0.0186	0.0106
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.0303	0.0265	0.0153
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.0296	0.0229	0.0130

Table 5-18 SUMMARY OF RESULTS - Tinker AFB, Tank 222, - 31 July & 1 Aug 01						
Run Number	1 31 July	2 31 July	3 31 July	4 1 Aug	5 1 Aug	6 1 Aug
Field Data Inputs:						
Barrier in Place (Y or N)	N	N	N	N	N	N
Fume Suppressant in Use (Y or N). If Y, then Surf. Tension (dynes/cm)	Y 27.5	Y 27.5	Y 27.5	Y 27.5)	Y 27.5	Y 27.5
Bath Surface Area (ft^2)	26.8	26.8	26.8	26.8	26.8	26.8
Bath Freeboard (inches)	7.5	7.5	7.5	7.5	7.5	7.5
Exhaust Intake Area (ft^2)	2.65	2.65	2.65	2.65	2.65	2.65
Barometric Pressure (in.Hg) - P_b	29.97	29.97	29.97	30.05	30.05	30.05
Stack Diameter (ft.) - D_s	1.83	1.83	1.83	1.83	1.83	1.83
S-Pitot Tube Correction (dimensionless)	0.84	0.84	0.84	0.84	0.84	0.84
Average Stack Differential Pressure (in.H_2O) - ΔP	0.62	0.64	0.60	0.59	0.56	0.63
$\Delta P^{0.5}$	0.78	0.79	0.73	0.76	0.74	0.79
Stack Temperature (°F) - T_s	82.7	88.3	91.8	82.0	86.5	89.5
Stack Static Pressure (in.H_2O) - P_s	-2.1	-2.1	-2.1	-2.0	-2.0	-2.0
Absolute Pressure (in.Hg) - P_a	29.82	29.82	29.82	29.90	29.90	29.90
Dry Gas Meter Volume Sampled (ft^3) - V_m	58.988	60.562	23.433	105.032	105.045	111.718
Average Dry Gas Meter Temperature (°F) - T_m	91.0	95.7	96.7	91.5	97.5	101.0
Dry Gas Meter Cal. Factor (dimensionless)	0.9922	0.9922	0.9922	0.9922	0.9922	0.9922
Orifice $\Delta H_@$ (in.H_2O)	1.7101	1.7101	1.7101	1.7101	1.7101	1.7101
Average Orifice Diff. Pressure (in.H_2O) - ΔH	0.76	0.78	0.14	2.25	2.12	2.38
Water Collected (gm) - V_{lc}	25.7	26.4	12.0	50.6	54.5	47.8
Sampling Time (min.) - θ	120	120	120	120	120	120
Nozzle Diameter (inches) – D_n	0.1875	0.1875	0.125	0.25	0.25	0.25
Total Impinger + Wash Volume (ml) - V_{tot}	425	395	378	359	366	338

Table 5-18: Tinker AFB - 31 July & 1 Aug 01 (Continued)

Flow Results:						
Average Stack Velocity (ft/sec) - V_s	44.55	45.36	42.08	43.34	42.39	45.05
Dry Standard Meter Volume (dscf) - V_{dscf}	56.26	57.28	22.09	100.72	99.61	105.35
Moisture in Sample (as a gas, ft^3) – M	1.21	1.24	0.56	2.38	2.56	2.25
Moisture in Sample (%) - M_p	2.10	2.12	2.49	2.31	2.51	2.09
Dry Molecular Weight - assumed - (lb/lb-mole) - MW_d	29.00	29.00	29.00	29.00	29.00	29.00
Wet Molecular Weight (lb/lb-mole) - MW_w	28.77	28.77	28.73	28.75	28.72	28.77
Stack Area (ft^2) – A	2.64	2.64	2.64	2.64	2.64	2.64
Actual Stack Flow Rate (acfm) - Q_a	7,060	7,180	6,660	6,860	6,710	7,140
Standard Stack Flow Rate (scfm) - Q_s	6,840	6,900	6,360	6,680	6,480	6,850
Dry Standard Stack Flow (dscfm) - Q_d	6,700	6,750	6,200	6,530	6,320	6,710
Isokinetic Rate (% of Isokinetic) - I	96.23	97.24	91.88	99.41	101.56	101.18
Laboratory Analysis:						
Total Chromium Concentration (mg/l) - C_t	0.410	0.0893	.0657	0.215	0.265	0.231
Hex.Chromium Concentration (mg/l) - C_h	0.399	0.0839	0.0557	0.192	0.242	0.214
Percent Hexavalent Chromium (%)	97.3	94.0	84.8	89.3	91.3	92.6
Mass of Total Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mt}	0.174	0.0353	0.0248	0.0772	0.0970	0.0781
Mass of Hex. Chromium Collected (mg) - (based on impinger + wash volume collected) - C_{mh}	0.170	0.0331	0.0211	0.0689	0.0886	0.0723

Table 5-18: Tinker AFB - 31 July & 1 Aug 01 (Continued)

Operational Parameters:						
Volts – E (avg. of 3 bath sections)	4.4	4.4	4.4	4.4	4.3	6.07
Average Amperes – AM (avg. of 3 bath sections)	136	138	140	149	119	1,466
Ampere-Hours (Amp-hr) – AH (total of 3 bath sections)	10,498	10,830	10,948	1,381	6,400*	6,230*
Hours Between AH Meter Readings - θ_{AH}	2.0	2.0	2.0	2.0	2.0	2.0
Amp-Hr. Normalized to the 2 Hour Test Period - (AH x $2/\theta_{AH}$)	10,498	10,830	10,948	1,381	2,815	6,230
Emission Results:						
Total Chromium Exhaust Concentration (mg/dscf) - C_{st}	0.00310	0.000616	0.00112	0.000766	0.000974	0.000741
Hex. Chromium Exhaust Concentration (mg/dscf) - C_{sh}	0.00301	0.000579	0.000953	0.000684	0.000889	0.000687
Total Chromium Exhaust Conc. (mg/dscm) - C_{st}	0.109	0.0217	0.0397	0.0271	0.0344	0.0262
Hex. Chromium Exhaust Conc. (mg/dscm) - C_{sh}	0.106	0.0204	0.0337	0.0242	0.0314	0.0242
Total Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_t	0.237	0.0461	0.0764	0.435	0.116	0.0958
Hex. Chromium Emitted/Amp-Hr (mg/Amp-hr) - CAH_h	0.231	0.0433	0.0648	0.388	0.105	0.0888

* The Amp-hr meter on the first bath circuit (222A) was broken during these two runs. Consequently, 5,000 amp-hrs was assumed for that section for each run, based on prior experience.

6. Cost Assessment

6.1 Cost Performance

The cost of implementing wetting agent/fume suppression (WA/FS) technology is shown in Tables 6-1 and 6-3. Table 6-1 is the cost for retrofitting WA/FS at existing facilities, such as the two facilities tested for this report (Cherry Point and Tinker). Table 6-3 is the costs that would be expected to implement WA/FS at new facilities. Startup costs are considered to be one-time costs; operation and maintenance (O&M) costs are shown on an annual basis for each hard chromium electroplating bath (assuming a bath surface area of about 25 square feet [ft^2], similar to the baths tested for this report). No demobilization costs are envisioned for either new or existing systems (see footnotes to Table 6-3).

The differences between the two tables reflect the assumption that an air pollution control device (APCD) will not have to be installed at a new facility in the electroplating bath exhaust system ductwork (i.e., the use of WA/FS would control emissions to a level that would, by itself, comply with air pollution control regulations). This assumption may be flawed, because the test results from this study indicate that in most instances uncontrolled emissions from baths using WA/FS did not comply with current USEPA emission standards (see section 5.1.2.1 and 5.2). For existing facilities two alternatives are shown (see last footnote to Table 6-1): (1) WA/FS technology is used in conjunction with the existing APCD (i.e., scrubber) system, and (2) the existing scrubber is, in effect, turned off when using WA/FS technology. The second alternative assumes that emission limits can be achieved by using WA/FS alone. Again, this assumption may be flawed.

Table 6-1: Costs of Implementing and Using WA/FS Pollution Prevention Technology at Existing Facilities (per 25-ft^2 bath)

Startup		Operation & Maintenance		Demobilization	
Activity	**Cost ($)**	**Activity**	**Cost ($/yr)**	**Activity**	**Cost ($)**
Labor	0	Labor	0	Removal of Equipment and Structures	N/A
Planning and Contracting	0	Monitoring	1,300	Site Restoration	N/A
Site Preparation	0	Analytical Services	0	Decontamination	N/A
Capital Equipment	800*	Equipment/Facility Modifications	0	Demobilization of Personnel	N/A
Construction	0	Utilities	0/(5,710)**		
Permitting and Regulatory Requirements	0/3,590**	Training to Operate Technology	0		
		Effluent Treatment and Disposal	0/(2,000)**		
		Residual Waste Handling and Disposal	0		
		Ancillary Equipment	0		
		Consumables and Supplies	(1,700)		
TOTALS:					
Startup (one-time):	800/4,390**	**O&M (annual):**	(400)/ (8,100)**	**Demobilization:**	0

N/A – not applicable
( ) – Indicates a negative cost; i.e., a savings
* Includes $300 for the cost of the one-time startup addition of WA/FS to each 800-gallon bath.
** For costs shown as x/y, "x" represents costs if there are no modifications made to the existing exhaust systems or APCDs; "y" reflects costs incurred if all APCD internals are removed, and scrubber water turned off.

The costs in Table 6-1 were calculated in the following manner:

Startup Costs:

- *Labor:* These are the costs that would be incurred in having to develop local process specifications for the use of WA/FS at each DOD facility. It is assumed that, realistically, no additional facility-based hires would be required for this one-time cost. Therefore the cost is assumed to be zero.
- *Planning and Contracting:* Beyond the labor noted above for developing local process specifications, there is no additional one-time planning and contracting envisioned.
- *Site Preparation:* No site preparation is required to implement the use of WA/FS.
- *Capital Equipment:* The use of WA/FS does not require any significant capital equipment. However, a one-time addition of WA/FS to each bath is required. For an 800-gallon bath (such as the baths at Cherry Point), two gallons of WA/FS (Fumetrol®

140) are required at about $150 per gallon, or a total WA/FS price of $300. In addition, to monitor the surface tension in the hard chromium bath, it will be required to purchase a deNouy Tensiometer, costing about $2,500. (The North Island facility uses a stalagmometer to measure surface tension. The stalagmometer costs only about $450.) Assuming that there are five baths in each shop, the cost per bath is $500. Therefore, the total "capital equipment" cost would be $800 per bath ($300 + $500).

- *Construction:* No additional construction is required to implement the use of WA/FS.
- *Permitting and Regulatory Requirements:* Existing facilities already have air emission permits based on the APCDs already in place (typically scrubbers). If the APCDs are not modified, the use of WA/FS will only enhance their performance. Hence, no additional permitting would be required. However, if it is decided that WA/FS performance is so good that the existing APCD internals can be removed (i.e., the scrubber packing), and that the scrubber water can be turned off, such modifications would require a new (or significantly modified) permit application. It is estimated that the cost of such permitting, which might require an environmental consultant, would require about 200 labor hours, at an average assumed labor cost of about $80 per hour, or about $16,000. If it is assumed that the average shop has five hard chromium baths that would be covered by such a permit, then the one-time per bath cost is $3,200. It is not anticipated that startup emissions monitoring would be required as a condition of permitting.

  In addition, regulatory requirements (based on decorative chromium plating regulations) would suggest that 10 tensiometer measurements would be required the first week of operation, and 5 measurements the second week, for a total of 15 measurements. Subsequent testing would be once per week (which is the current practice at North Island where WA/FS is used routinely) as long as there were no exceedences. The once per week measurements are included under O&M costs, below. It is assumed that for a 5-bath shop, one set of measurements would require two labor-hours (for reference, North Island and Tinker indicate 30 minutes per bath); therefore, 15 sets would require 30 hours. At $65 per hour (based on a rough average of Cherry Point and North Island labor rates), the total cost would be $1,950, or $390 per bath. This cost would not be required if the current APCD were left in place.

  Therefore, total permitting and regulatory issues would cost $3,590 ($3,200 + $390) per bath if the APCD internals were removed, and scrubber water flow ceased.

O&M:

- *Labor:* The only labor required for the use of WA/FS (other than monitoring and training, shown below) is the time required to add WA/FS to maintain the proper surface tension. It is estimated that this is about ½ hour per week. Realistically, this would require no additional hires, having in effect, no significant cost.
- *Monitoring:* The only routine monitoring requirement is the weekly determination of surface tension in each hard chromium bath. It is expected that this procedure, using the deNouy Tensiometer, will take 2 hours each week for a shop with five baths. Realistically, it is unlikely that this procedure would require a new hire. However, if a new hire were required, at an estimated $65 per hour, the annual cost per bath for a 50-week year would be $1,300. Routine emissions monitoring would not be an anticipated

requirement on an existing electroplating operation that was equipped with WA/FS technology.

- *Analytical Services:* The use of WA/FS should not require any additional analytical services beyond what are already required for hard chromium bath maintenance.
- *Equipment/Facility Modifications:* No modifications to electroplating shop operations and maintenance procedures will be required when using WA/FS.
- *Utilities:* If the scrubber internals were left in place there would be no change in the use of electricity to operate the exhaust fan, nor would there be any reduction in the flow of scrubber water. However, if scrubber internals are removed, fan speed cut back to maintain the same volumetric flow (but at a lower pressure drop), and scrubber water were no longer used, the cost savings would be \$5,710 per year per bath, calculated by adding items (1) and (2) below. (No costs have been assigned the work required to lower the fan speed. It is assumed that such one-time costs will balance the value of the additional life the fan will realize by running more slowly.)

  (1) Assuming: an average ventilation rate of 7,000 dry standard cubic feet per minute (dscfm) per bath (approximate average of each bath at Cherry Point and Tinker), an assumed reduction in exhaust system pressure drop of five inches of water (in.H_2O) (North Island currently averages a 7.5 in.H_2O pressure drop across its scrubber), 365 day per year/24 hours per day operation (typical of Cherry Point and Tinker; in fact the baths are ventilated even when there is no electroplating taking place), 60% fan/motor efficiency (typical for radial bladed centrifugal fans), and 8.3¢ per kilowatt-hr (kwh) (based on Federal Trade Commission 5/21/01 national average estimates) – then a savings of about 9.2 horsepower and \$5,000 per year of electrical costs would be realized per bath.

  (2) Assuming: the cost of water is \$3 per thousand gallons (based on an approximate average of Cherry Point and North Island costs), the scrubber make up is 2 gallons per minute (gpm) (based on Cherry Point data), the scrubber services all five hard chromium baths, and the scrubber operates 365 days per year/24 hours per day – then a savings of \$630 per year would be realized per bath. In addition, the scrubber water recirculation pumps, recirculation sump heaters, and pipe tracing power would no longer be needed either, saving the cost of electricity and maintenance for these items. These savings are estimated to be about \$80 per year per bath based on Cherry Point records.
- *Training:* Assume about three labor-hours per year for each facility (i.e., 1 hour per shift with 3 shifts) to acquaint operating labor with the use and addition of WA/FS. Realistically, this would require no additional hires, having in effect, no cost, especially on a per-bath basis.
- *Effluent Treatment and Disposal:* Cherry Point estimates that it costs about \$15,800 annually to treat the scrubber blowdown at their industrial waste treatment facility. This cost would be avoided if the scrubber could be taken out of service. On a per-bath basis this savings would be about \$3,200 per year. North Island estimates that only about 350 gallons per day are blown down from the scrubbers and treated daily. At an estimated treatment cost of \$6.55 per thousand gallons, this equates to only about \$170 per bath per year. Based on these two estimates (i.e., \$3,200 and \$170) a value of \$2,000 per bath per year is assumed.
- *Residual Waste Handling and Disposal:* Hazardous waste sludges are created when the scrubber water blowdown is treated at the industrial waste treatment facility. The costs

of disposing of these sludges probably exceed $400 per ton. However, for Cherry Point, that cost is already included in the cost of effluent treatment and disposal, as discussed above. This is assumed to be the case for other facilities as well.

- *Ancillary Equipment:* No ancillary equipment is required to implement the use of WA/FS (other than the tensiometer discussed above).
- *Consumables and Supplies:* The use of WA/FS minimizes the loss of chromic acid to the exhaust system (i.e., to the scrubber) from the hard chromium baths. Based on sampling data (see Table 6-2), between 120 and 460 pounds per year of chromic acid are saved per year per bath when using WA/FS, at a cost of $7 per pound. (For reference, Cherry Point pays $7.00 per pound of chromic acid. The Chemical Marketing Reporter indicates that chromic acid in 50-pound bags is $17.50 per pound. North Island claims that they pay $91 per 50-lb.can, or $1.82 per pound.) This amounts to an average saving of over $2,000 per year per bath (assuming that the baths are in service 50 percent of the time).

  However, it is necessary to maintain the appropriate surface tension in the bath, so as to maintain the chromic acid savings. It is estimated that an 800-gallon bath should require about 2 gallons of WA/FS annually to maintain the proper surface tension. At $150 per gallon, the annual cost will be $300. Therefore, the net savings on consumables and supplies is estimated to be $1,700 ($2,000 minus $300).

Table 6-2: Analysis of Emissions Data and Projected Cost Savings From Use of Fume Suppressant

Set Sampling Date	Average Air Flow (dscf/min)/ (dscm/min)	Tot. Chromium Concen. (mg/dscm)	Emitted Mass of Chromium w/o WA/FS (mg/min)	Emitted Mass of Chromium with WA/FS (mg/min)	Amount of Chromic Acid Saved (lb/yr) & Cost Savings ($/yr)
Cherry Point Stack Samples					
7/11/00	4,890/138	3.83	530		
7/12/00	4,890/138	2.18	302		
9/21/00 FS*	6,760/191	0.0362		6.93	
11/15/00	5,980/169	1.36	231		
11/16/00 FS	6,840/194	0.0527		10.21	
12/13/00 FS	6,240/177	0.0242		4.28	
3/27/01 FS	7,810/221	0.0415		9.18	
4/17/01 FS	7,380/209	0.0197		4.12	
Average Chromium Emission:			354	6.94	**456**
		Cost Savings per year @ $7/lb and 50% bath use:			**$3,194**
Tinker Stack Samples					
9/12/00	7,400/210	0.474	99		
10/11/00 FS	7,740/219	0.0108		2.37	
11/8/00 FS	7,480/212	0.0061		1.30	
12/6/00 FS	7,280/206	0.0193		3.98	
7/31/01 FS	6,550/185	0.0568		10.54	
8/1/01 FS	6,520/185	0.0292		5.39	
Average Chromium Emission:			99	4.71	**124**
		Cost Savings per year @ $7/lb and 50% bath use:			**$867**

* FS signifies that fume suppressant was used for this series of tests.

Demobilization Costs:

No significant costs are associated with WA/FS use when demobilizing an electroplating line. No equipment must be removed beyond what was already in place prior to the use of WA/FS.

Table 6-3: Costs of Implementing and Using WA/FS Pollution Prevention Technology at New Facilities (per 25-ft^2 bath)

Startup		Operation & Maintenance		Demobilization	
Activity	**Cost ($)**	**Activity**	**Cost ($/yr)**	**Activity**	**Cost ($)**
Labor	0	Labor	0	Removal of Equipment and Structures	N/A
Planning and Contracting	0	Monitoring	1,300	Site Restoration	N/A
Site Preparation	0	Analytical Services	0	Decontamination	N/A
Capital Equipment	800*	Equipment/Facility Modifications	0	Demobilization of Personnel	N/A
Construction	(46,000)***	Utilities	(5,710)		
Permitting and Regulatory Requirements	0	Training to Operate Technology	0		
		Effluent Treatment and Disposal	(2,000)		
		Residual Waste Handling and Disposal	0		
		Ancillary Equipment	0		
		Consumables and Supplies	(1,700)		
TOTALS:					
Startup (one-time):	(45,200)	**O&M (annual):**	(8,100)	**Demobilization:**	0**

N/A – not applicable
* Includes $300 for the cost of the one-time startup addition of WA/FS to each 800-gallon bath.
** In fact, there is a distinct cost savings for demobilizing new hard chromium plating operations that use WA/FS, and therefore, do not use scrubbers; i.e., there are no scrubbers and associated equipment to demobilize at the end of the useful life of the hard chromium plating operation. However, these savings are not included in this analysis.
*** Construction cost savings reflects the fact that the cost of capital equipment (a scrubber and associated equipment) plus installation is not required.

The costs in Table 6-3 were calculated in the following manner:

Startup Costs:

All elements of startup costs for new hard chromium installations are identical to those shown in Table 6-1 for existing systems where the scrubber has been taken out of service, except as follows:

- *Construction:* There are significant one-time cost savings during construction because it is assumed that a scrubber does not have to be installed, and a smaller fan/motor can be used (since the pressure drop associated with a scrubber no longer exists). Note that this assumption may be flawed, as explained in the second paragraph of Section 6.1. Cherry Point estimated that the installed cost of the scrubber system (not including fan and ductwork, which will be required for any ventilation system) for their five hard chromium electroplating baths was $175,000 when installed. For North Island the scrubber system capital cost was estimated at $500,000, including fan and ductwork, and including a second scrubber system for non-chromate bath fumes (e.g., from hot alkaline cleaners). It is therefore expected that the North Island costs are in line with the Cherry Point costs, or about $200,000 for the relevant system parts. Hence, the average cost of a scrubber system for emissions from hard chromium electroplating would be about $200,000 for an installed scrubber and high pressure drop fan. Since the systems were installed at least five years ago, it is reasonable to assume that current costs would be about $230,000 (3.2% escalation for 5 years). Therefore, the startup cost savings per bath is estimated to be $46,000.
- *Permitting and Regulatory Requirements:* It is estimated that a new system installed with or without the use of WA/FS technology would still require approximately the same level of effort to obtain permitting. Hence, there is no additional cost (or savings) associated with permitting a WA/FS-equipped system, as opposed to a scrubber-equipped system.

O&M:

The operating and maintenance costs associated with a new hard chromium electroplating bath system equipped with WA/FS technology are essentially the same as for retrofitting an existing system. One might argue that there would be additional electricity cost savings on a new system, since the fan/motor on a new system could be designed to be the right size rather than slowing down the speed of an existing fan. However, this degree of detailed analysis is difficult to perform. Therefore, it is assumed, conservatively, that the electricity savings is $5,710 per year, as it was when retrofitting an existing system.

Demobilization Costs:

Demobilization costs for new systems are assumed to be zero. In fact, there is a distinct cost *savings* for demobilizing new hard chromium plating operations that use WA/FS instead of scrubbers; i.e., there are no scrubbers and associated equipment to demobilize at the end of the useful life of the hard chromium plating operation. Conservatively, however, these savings are not included in this analysis.

6.2 Cost Comparisons to Conventional and Other Technologies

Table 6-4 summarizes the relative costs and savings shown in Tables 6-1 and 6-3 for the three different scenarios in which WA/FS technology is used. Tables 6-1 and 6-3 both compare the use of WA/FS technology to the conventional technology of using a wet scrubber (or similar

APCD) in the exhaust ductwork. Table 6-1 evaluates two scenarios for *existing* hard chromium electroplating baths, and Table 6-3 evaluates the use of WA/FS in *new* electroplating systems.

Table 6-1 gives two cost alternatives relating to the use of WA/FS on existing hard chromium electroplating baths. The first alternative is for using WA/FS in addition to the existing scrubber. Even though this approach might not appear to be economical, in fact it is economical because the WA/FS prevents the loss of chromic acid plating solution. Specifically (see Table 6-1 Totals), there are one-time startup costs of $800, and annual O&M *savings* of $400. If it is assumed that the bath/scrubber system have a 10-year effective life cycle, and that the Real Discount Rate used by federal government agencies is 3.2 percent per year (OMB Circular A-94), then the effective annual equivalent cost of the $800 startup cost is $95. Therefore, the effective annual *saving*, per bath, of this alternative is about $300 per year ($400 minus $95). This savings represents a payback of the $800 startup costs of fewer than three years.

The second alternative presented in Table 6-1, in which the scrubber system is, in effect, shut off, will have an effective annual *savings*, per bath, of about $7,600. (The 4,390 startup costs have an annualized value of $520, subtracted from the annual O&M savings of $8,100.) This savings represents a payback period of the $4,390 startup costs of less than seven months.

Table 6-3 shows that for a new installation one-time startup costs are about $45,200 *less* than for a conventional system with a scrubber. In addition, about $8,100 in O&M savings occurs every year. The effective annual *savings* are therefore, about $13,450 per bath. (The annualized value of the $45,200 savings is about $5,350, plus the $8,100 annual O&M savings.) Since the startup costs are less than a conventional scrubber system would be, “payback period” is not relevant.

Again, it should be noted that the savings attributable to shutting off existing scrubbers, or not installing scrubbers on new hard chromium electroplating operations, may not be available. This is because emissions from hard chromium electroplating baths using WA/FS, as measured in this study, while improved by 20-to 70-fold as compared to baths without WA/FS, still do not routinely comply with USEPA hard chromium quantitative emission standards.

Table 6-4: Summary of Annual Savings When Using WA/FS (Dollars per hard chromium plating bath)*

	Existing Hard Chromium Line		New Hard Chromium Line***
	WA/FS plus scrubber	WA/FS with scrubber disabled	
Startup Costs	800	4,390	(45,200)
Annualized Startup Costs/Savings**	95	520	(5,350)
Annual O&M Costs/Savings	(400)	(8,100)	(8,100)
Total Annual Cost/Savings	(300)	(7,600)	(13,450)
Payback Period (years)	2.7	0.6	N/A

* Savings are in parentheses ( ).
**Annualized costs/savings are calculated based on 10 years equipment life for capital equipment, and a Real Discount Rate of 3.2% per year.
*** Assumes that an APCD (i.e., a Scrubber System) will not be required.

7. Regulatory Issues

Currently, DOD hard chromium electroplating baths have air emissions permits for discharging to the atmosphere (see section 1.3 for regulatory standards). Using WA/FS will not, under current and foreseeable future USEPA regulations, eliminate the need for these permits. Even though the use of WA/FS and will undoubtedly lower the amount of chromium exhausted to air pollution control devices (APCDs), it will probably not be any less time consuming to obtain new or renewal permits from permitting agencies. However, DOD should persist in efforts to convince USEPA to allow the use of WA/FS *instead of* APCDs, as USEPA has done for *decorative* chromium electroplaters. If successful in these efforts there would be potentially great savings in being able to "turn off" existing APCDs, or in not having to install APCDs on any new hard chromium electroplating baths. With respect to this project, USEPA's Risk Management Research Laboratory (RMRL), in Cincinnati, Ohio (Mr. David Ferguson) has consulted with the Naval Facilities Engineering Service Center (NFESC) Project Coordinator (Ms. Kathleen Paulson). The project Demonstration Plan was reviewed and coordinated with RMRL. It is hoped that the results of this study will be used by USEPA to support a regulatory change such that WA/FS may be used in hard chromium electroplating as an alternative to APCDs.

It is recognized that most of the emissions data developed in this study while using only WA/FS technology would not meet the current USEPA criterion for chromium emissions. However, the improvement in chromium plating bath emissions is so great with WA/FS, that it is conceivable that minor modifications in operating practices might allow the achievement of USEPA's criterion. Specifically, providing an additional inch or two of freeboard might assist in keeping mist from exhaust system intakes. Likewise, mixing baths mechanically (e.g., with recirculating pumps or mixers) instead of with air would eliminate aeration as a source of mist. (Mechanical mixing is already practiced at North Island.)

With respect to OSHA compliance relative to in-plant emissions of hexavalent chromium, this study has shown that WA/FS lowers the amount of hexavalent chromium available for respiration by workers. This might allow hard chromium electroplating baths to operate with less exhaust volume, and still comply with OSHA regulations (current or proposed). This would be a benefit for new hard chromium installations, but probably result in no practical savings for existing installations. Although, for existing installations (or new installations whose ventilation systems are designed to current ventilation standards), the use of WA/FS should lower workman compensation liability with respect to hexavalent chromium respiratory illness claims.

With respect to the use of WA/FS, USEPA has issued a proposed rule (65 FR 62319, 18 Oct 2000), *Perfluorooctyl Sulfonates; Proposed Significant New Use* that could affect the use of the WA/FS tested for this project (Fumetrol® 140). The proposed rule would require that manufacturers of perfluorooctyl sulfonate (PFOS) compounds notify USEPA before commencing manufacture of these substances. USEPA is concerned that these compounds, which appear to be the primary active ingredient in Fumetrol® 140, may be "hazardous to human health and the environment". However, the regulation appears to target the primary use of PFOS, which is the treatment of fabrics and paper to provide soil and water resistance. This proposed rule has no immediate effect on the use of WA/FS. However, it is conceivable the

proposed rule might lead to banning or reducing the use of such compounds for certain uses. The recommended dosage of Fumetrol® 140 for hard chromium electroplating baths is only 0.25 percent. Therefore, it is unlikely that such low concentration use would ever be regulated for hard chromium operations, especially since its function is to significantly reduce the environmental and occupational exposure to a known carcinogen, hexavalent chromium.

8. Technology Implementation

8.1 DOD Need

Sections 5 and 6 of this report show that the use of WA/FS (specifically Fumetrol® 140) is likely to cause atmospheric emissions of hexavalent chromium from hard chromium electroplating baths to be reduced by one to two orders of magnitude. This emission reduction will have obvious health benefits to the employees in the electroplating shops. In addition, using WA/FS has the potential, in new electroplating installations, to eliminate the need for air pollution control devices (APCDs), and their inherent capital and operating costs. For existing shops, the use of WA/FS may allow existing APCDs to be taken out of service, eliminating current APCD operating costs. For all shops, there will be an immediate savings in the cost of chromic acid replacement, because losses of chromic acid mist to the atmosphere will be minimized. Additionally, section 5.1.4 shows that the use of Fumetrol® 140 does not appear to have any measurable negative effect on the quality of hard chromium electroplated parts.

It would appear that there are many health and financial advantages for DOD to use WA/FS in hard chromium electroplating baths, and few, if any, downside risks.

8.2 Transition

Each DOD facility would need to implement the use of WA/FS based on the protocols for the particular DOD branch (i.e., Army, Navy, Air Force, Marines, Coast Guard). For NAVAIR, for example, approval for implementation of Fumetrol® 140 is planned to be accomplished by issuing a formal Navy message that details engineering concurrence from NAVAIR Materials, Structures and Subsystems Divisions based on data provided by this project. This concurrence is planned to extend to the support of NAVAIR OEMs in the construction and repair of NAVAIR aircraft and supporting equipment. Each facility will need to change their local process specifications to accommodate the QA/QC of the bath concentration and surface tension monitoring.

9. Lessons Learned

9.1 Bath Maintenance Effects Surface Tension

It was the original intention of this study to do one baseline test (i.e., without WA/FS) at each of the facilities tested (Cherry Point and Tinker). Subsequent testing at both facilities was expected to be only with WA/FS in the baths. At Cherry Point, however, the facility was not able to reduce the surface tension to below the desired 30 dynes per centimeter range in the bath being tested (Tank 155). After the baseline test, 33 dynes per centimeter appeared to be as low as the facility could achieve by adding WA/FS. Consequently, the bath was changed out, and replaced with fresh components. Another baseline test was run (on 15 Nov 2000), and then WA/FS was added for subsequent testing. On the fresh bath surface tensions between 23 and 27 dynes per centimeter were achieved.

At the time the original Tank 155 was put into service, and for several years of use, tap water was used to make up for evaporation and dragout. Therefore, it was concluded that the buildup of dissolved salts from the tap water (e.g., magnesium, calcium, trace metals, anions) reduced the ability of the WA/FS to effectively lower the surface tension. In support of this conclusion, section 5.1.5.2 of this report presents constituency data for Tank 099 at Cherry Point. Tank 099 is another chromium plating bath that did not contain WA/FS, but was sampled to compare the constituency of various chromium electroplating baths. Tank 099, which probably has the same history as the original bath contents in Tank 155, has a significantly higher concentration of trace metals than the other chromium electroplating baths that were analyzed.

This experience suggests that surface tension reduction may not be achievable in chromium electroplating baths with excessive amounts of contamination, or unless dragout and evaporation are replaced with distilled or deionized water, as they are at Tinker and North Island. (Cherry Point also recently converted to deionized water.)

9.2 Other Observations

The question often raised about the emission of mist from electroplating baths is whether the misting is due primarily to electrical activity at the anodes and cathodes (i.e., the production of hydrogen and oxygen gases), or from mechanical aeration of the baths to facilitate mixing. The answer became apparent inadvertently during the first day of baseline testing (i.e., testing without WA/FS) at Cherry Point (11 July 2000). During the first of the three tests on that day there was no electroplating load in the bath. However, the bath was aerated. The emissions from that test were 0.0454 milligrams per dry standard cubic meter (mg/dscm) of hexavalent chromium. The two following tests, under the same conditions, except with loads in the bath, were 6.32 and 0.737 mg/dscm respectively, at least more than one order of magnitude higher than with aeration alone. These data would suggest that emissions from electrolytic activity are far more significant than from mechanical aeration.

10. References

1. Chromium Emissions from Chromium Electroplating and Chromic Acid Anodizing Operations-Background Information for Proposed Standards (EPA 453/R-93-030a), Volume 1, July 1993.

2. David Ferguson, Matthew Zellen, Dawn Brennan, Janette Lutz. *Use of Fume Suppressants in Hard Chromium Baths-Quality Testing*. Plating and Surface Finishing. Feb 2000, Vol 87, No. 2, pp 67-72.

3. David Ferguson, Briana Sprague, Dawn Brennan, Janette Lutz. *Use of Fume Suppressants in Hard Chromium Baths-Emission Testing*. Plating and Surface Finishing. Jan 2000, Vol 87, No.1, pp 72-74

4. Circular No. A-94, Revised (Transmittal Memo No. 64), Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, Memorandum for Heads of Executive Departments andEstablishments,http://www.whitehouse.gove/omb/circulars/a094/a094.html,October29, 1992.

5. Determination of Chromium Emissions from Decorative and Hard Chrome Electroplating and Anodizing Operations, USEPA Method 306. http://www.epa.gov/ttn/emc/promgate/m-306.pdf

6. Hexavalent Chromium in Workplace Atmospheres. OSHA Method 215, Occupational Safety andHealthAdministration.http://www.osha-slc.gov/dts/sltc/methods/inorganic/id215/id215.html. June 1998

7. John R Mulhausen, Joseph Damiano. *A Strategy for Assessing and Managing Occupational Exposures.* American Industrial Hygiene Association. 1998.

8. *Chromium Plating (Electrodeposited*). Federal Specification QQ-C-320B(4). http://astimage.daps.dla.mil/quicksearch/basic_profile.cfm?ident_number=50938. Naval Air Systems Command. 10 April 1987

9. Guide To The Navy Industrial Hygiene Field Operations Manual. Naval Environmental Health Center. http://www-nehc.med.navy.mil/ih/ihfom99.htm. 1999

APPENDIX A

POINTS OF CONTACT

The following individuals, their organizations, their roles, addresses, phone numbers, and e-mail addresses are listed in the following table.

Name	Organization/Code	Phone Number	E-mail Address	Fax Number	Street Address	Role in Project
Principal Investigators						
Kathleen (Kappy) Paulson	NFESC/NAVOSH Engineering (ESC425)	805-982-4984 DSN 551-4984	paulsonkm@nfesc.navy.mil	805-982-1409	1100 23rd Street, Port Hueneme, CA 93043	Project Coordinator
Craig Matzdorf	NAVAIR/ Code 4.3.4.1 Aerospace Materials Division	301-342-9372	matzdorfc@navair.navy.mil	301-342-7566	48066 Shaw Rd Patuxent River, MD 20670	Materials Evaluation
T. David (Dave) Ferguson	EPA Risk Management Research Lab	513-569-7518	ferguson.david@epa.gov	513-569-7471	26 W. M.L. King Dr. Cincinnati, OH 45268	EPA Consultant on field testing
Roger C Wilmoth	NRMRL, Multimedia Technology Branch Chief	513-569-7509	wilmoth.roger@epa.gov	513-569-7471	26 W. M.L. King Dr. Cincinnati, OH 45268	
Air Logistics Center - Tinker AFB, Oklahoma City, OK						
Glen Graham	ALC-OKC	405-736-2018 DSN 336-2018	Glen.Graham@tinker.af.mil	405-736-2501	Attn: Glen H. Graham OC-ALC / LPPEE 3001 STAFF DRIVE POST 2B93 TINKER AFB, OK 73145 - 3034	Materials Engineer Tinker Contact
Tom Morris	ALC-OKC	405-736-2503	tom.morris@tinker.af.mil		same as G. Graham	Facilities Manager
Ernest Barlor	ALC-OKC	405-736-5280 DSN 336-5280	earnest.barlor@tinker.af.mil note: name is *incorrectly* spelled in e-mail address		Attn: Ernest Barlor OC-ALC / LPPPCH 3001 STAFF DRIVE POST 2B93 TINKER AFB, OK 73145 - 3034	Solution Maintenance Sub unit
Jerry Jones	ALC-OKC	405-736-3489 405-736-2135	jerry.jones@tinker.af.mil chris.mance@tinker.af.mil			Plating Chemistry Laboratory
Don Riddle		405-734-7844	don.riddle@tinker.af.mil			Safety Manager
NADEP Cherry Point, NC						
Jesse Garman	NADEP Cherry Point, NC	252-464-9886	garmanjs@navair.navy.mil	255-464-8108	Code 4.3.4.4 PSC Box 8021	Materials Chemist Cherry Point POC

Name	Organization/Code	Phone Number	E-mail Address	Fax Number	Street Address	Role in Project
					Cherry Point, NC 28533-0021	
Robert (Yogi) Kessler	NADEP CP	252-464-9888	kestlerre@navair.navy.mil	255-464-8108	PSC Box 8021 Cherry Point, NC 28533-0021	Cherry Point Back-up POC
Beth Holland	NADEP Cherry Point	252-464-7037	hollandem@navair.navy.mil		Command Support Office Code 6.8	Cherry Point, Safety & Occ Health Department
Ken Lewis	NADEP Cherry Point	252-464-8114	Lewiskb@navair.navy.mil		Production Department Code 6.2.936	Cherry Point Plating Facility Supervisor
NADEP North Island, San Diego, CA						
Gary Kuhlman	NADEP North Island, CA	619-545-9733	Kulhmangr@navair.navy.mil		Code 43400 Building 464-1 San Diego, Ca 92135	Materials Lab POC
Ernie Shiwanov	NADEPNI/43420	619-545-7834	Shiwanove@navair.navy.mil		"	Chem/Materials Engineer
Ed Duffey	NADEPNI/43410	619-545-9760	Duffyer@navair.navy.mil		Code 4341	Metallurgist/Enginieer
Cathy Jennings	NMCSD/PCB	619-545-108?				Industrial Hygienist
Don Chateau	NADEP/61614	619-545-588	Chateaudt@navair.navy.mil		Code 61600 Bldg 90-2	NADEPNI Facilities
Michele Merien Mike Stagg	NADEP/09200	619-545-2234 619-545-3342				NADEPNI Air Pollution
Lary Lai	NADEP/08213	619-545-9200				NADEP-NI Environmental
Joe Everett	NADEP/	619-545-4251 DSN 735-4251	everett_j@a1.nadepni.navy.mil	619-545-5479	PO Box 357058 San Diego CA 92135-7058	Processing Prod Center Electroplater Supervisor Pager 619-979-4058
Larry Lausin	NADEP/61226	619-545-3053 DSN 735-3053	lausinl@navair.navy.mil	619-545-5399	PO Box 357058 San Diego CA 92135-7058	Industrial Equipment Mgr. Equipment Management Office Building 90-2
Horace Hill	NADEP/	619-545-3694 DSN 735-3693	hillh@navair.navy.mil	619-545-3695	"	OSH Specialist Pager 619-979-4735
Contractors						
Stephen M. (Steve) Schwartz	Versar, Inc	703/642-6787	schwaste@versar.com	703/642-6954	6850 Versar Center Springfield, VA 22151-4196	Contractor directing IH & Environmental field testing
Jennifer Brown	Versar Inc	703/642-6809	brownjen@versar.com	703/642-6891	"	CIH
Bryan Arnold	Versar Inc.	630/268-8555	arnolbry@versar.com	630/268-0555	200 West 22nd Street, Suite 250	CIH

Name	Organization/Code	Phone Number	E-mail Address	Fax Number	Street Address	Role in Project
					Lombard, IL 60148	
Laboratories						
George Lindsay	NEPMU 2, Norfolk	757/444-7671x3038	lindsayg@nepmu2.med.navy.mil	757/444-1556	NEPMU 2/ CHIL 1887 Powatan Street Norfolk, VA 23511-3394	Lab Director
Chuck Kubrock	NEPMU5, San Diego	619/556-1334		619/556-1492	NEPMU 5/ CHIL Naval Station, Box 368143 3235 Albacore Alley San Diego, CA 92136-5199	Lab Director
Dr Kate Luk	Research Triangle Institute	919/541-6569	kkl@rti.org	919/541-7215	3040 Cornwallis Rd., PO Box 12194, Research Triangle Park, NC 27709-2194	Analytical Laboratory Coordinator

APPENDIX B

DATA ARCHIVING AND DEMONSTRATION PLAN

For a minimum of 10 years after completion of the project, all environmental and occupational safety and health test results will be stored at Naval Facilities Engineering Service Center, Port Hueneme, California. Additionally, the approved Demonstration Plan (dated 15 October 2000) will be stored at the same location. For a minimum of 10 years after completion of the project, all material quality test results will be stored at Naval Aviation Systems command, Becker Laboratory, Patuxent River, Maryland. Project records will be kept in Mr. Craig Matzdorf's files at NAVAIR Laboratory. Testing records will be filed in the Inorganic Coatings Laboratory with Mr. Matzdorf. Stored materials will include all magnetic and hard copies of data, calibrations, equipment maintenance records calculations, records of original observations, final test results and miscellaneous quality records directly associated with sample analysis. An e-mail file of major correspondence will also be preserved with the magnetic material.

In the case of personnel changes, NFESC has a SERDEP/ESTCP Program Manger. Project materials will be turned over to the responsible individuals. At NAVAIR, project records will be turned over to the Materials Protection Branch Head. Test records will remain a part of the Inorganic Coatings Laboratory per NAVAIR Materials Division's, Quality System.

APPENDIX C

PHOTOGRAPHS

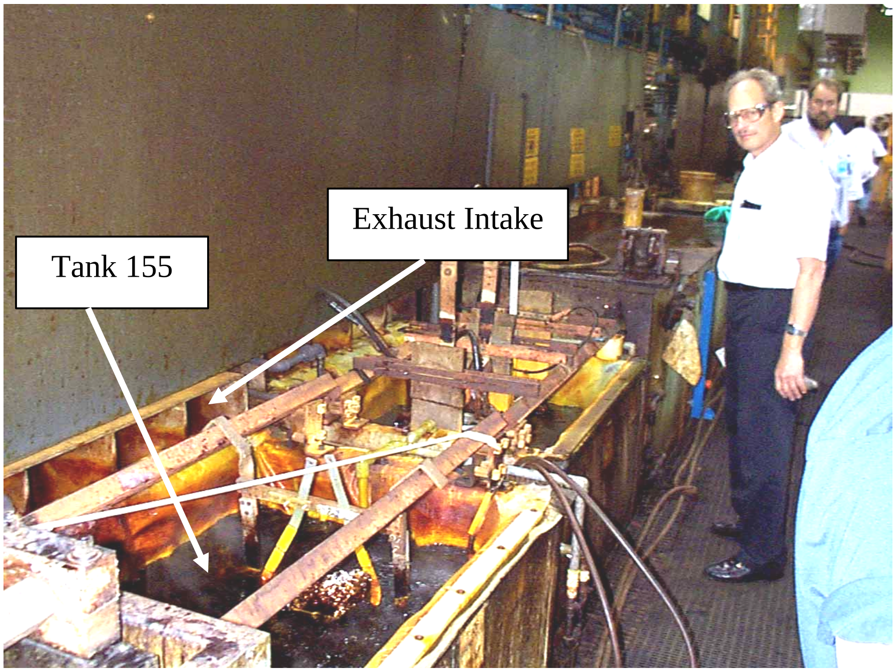


Figure 1 – CHERRY POINT, TANK 155

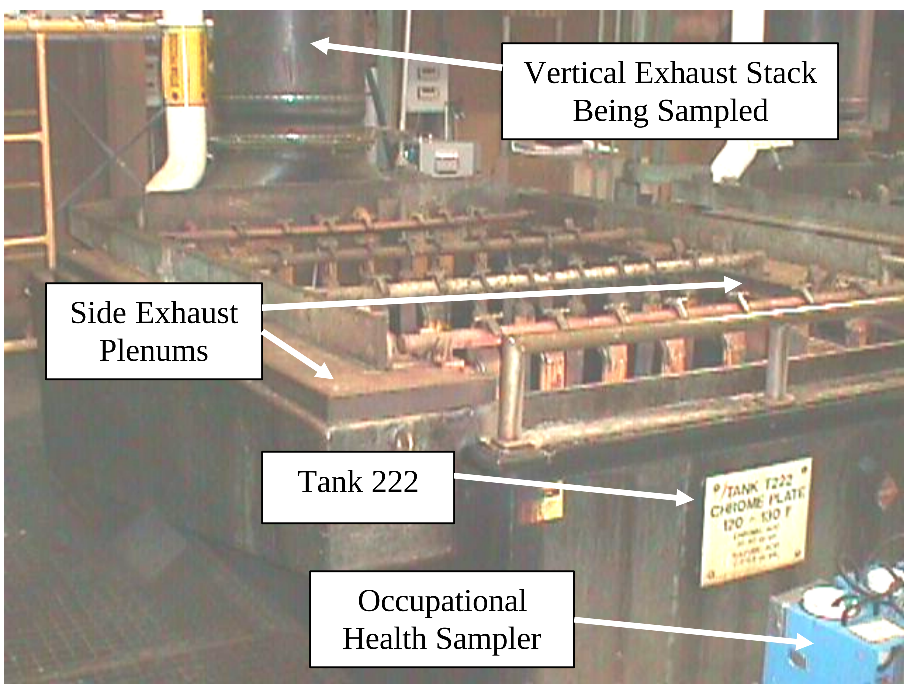


Figure 2 – TINKER, TANK 222

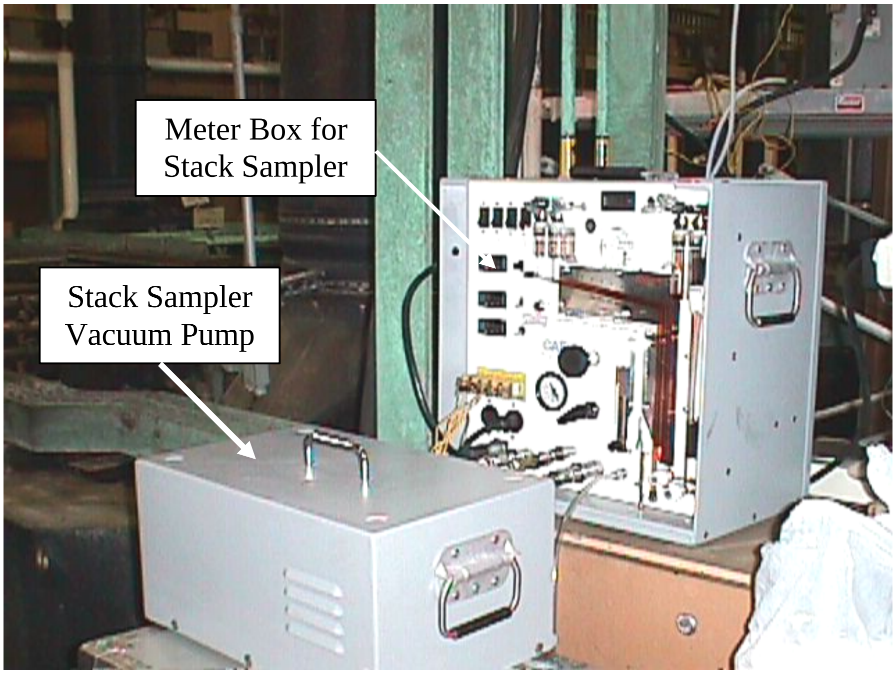


Figure 3 – STACK SAMPLER METER BOX AND PUMP (at TINKER)

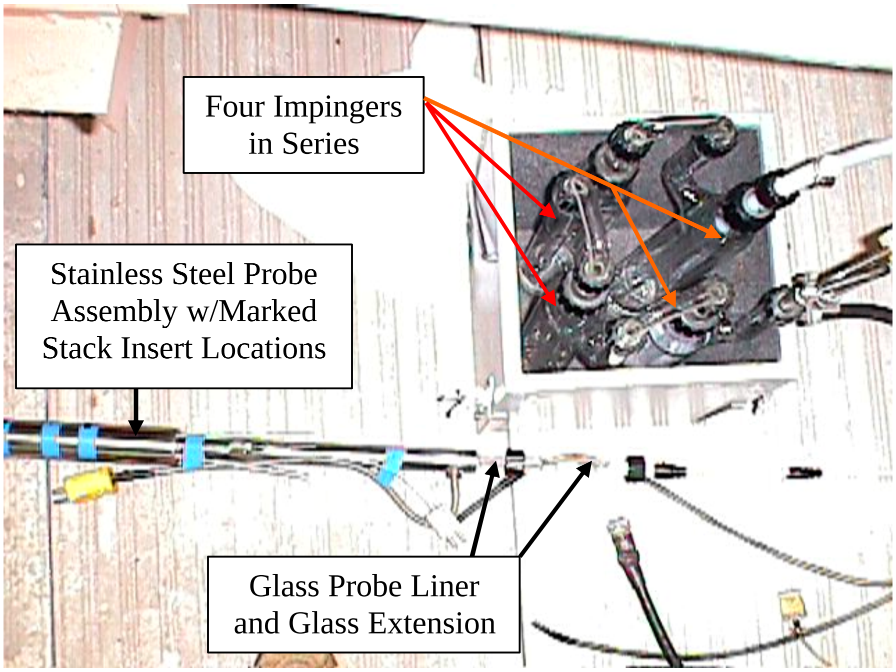


Figure 4 – IMPINGER CASE FOR STACK SAMPLER AND PROBE ASSEMBLY

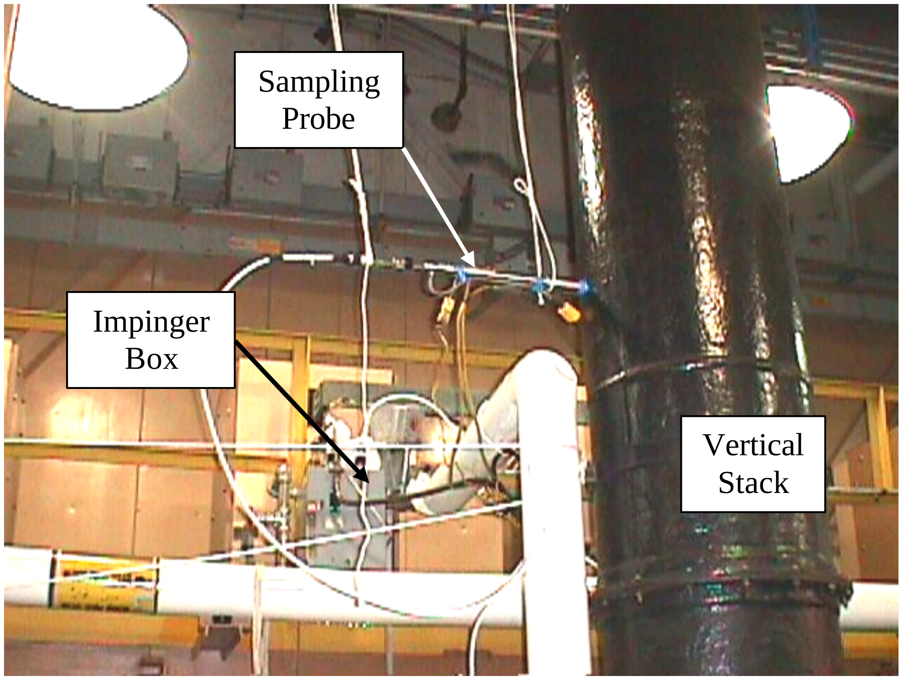


Figure 5 – STACK SAMPLING ASSEMBLY (at TINKER)

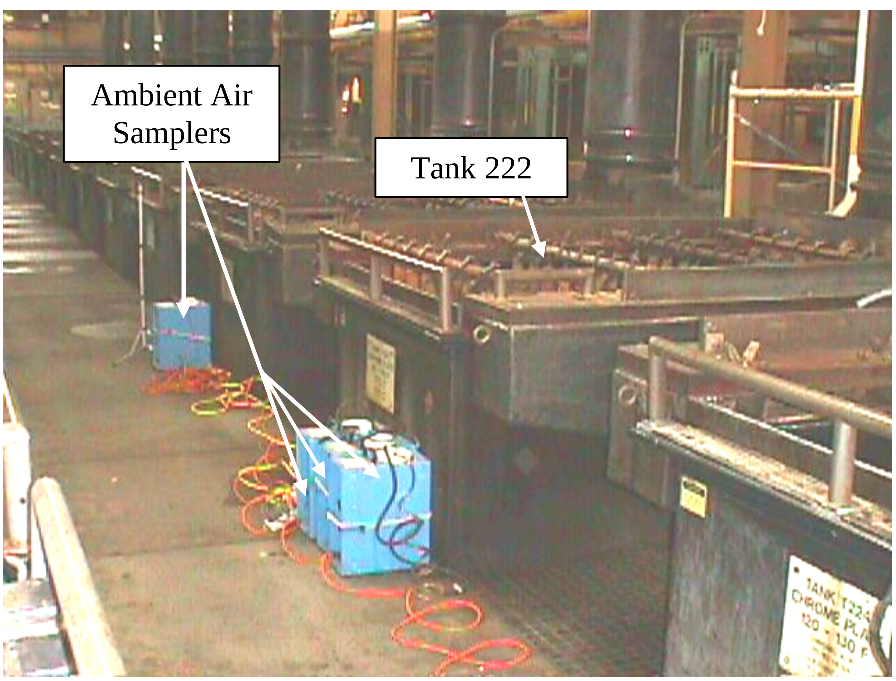


Figure 6 – OCCUPATIONAL HEALTH SAMPLING EQUIPMENT (at TINKER)

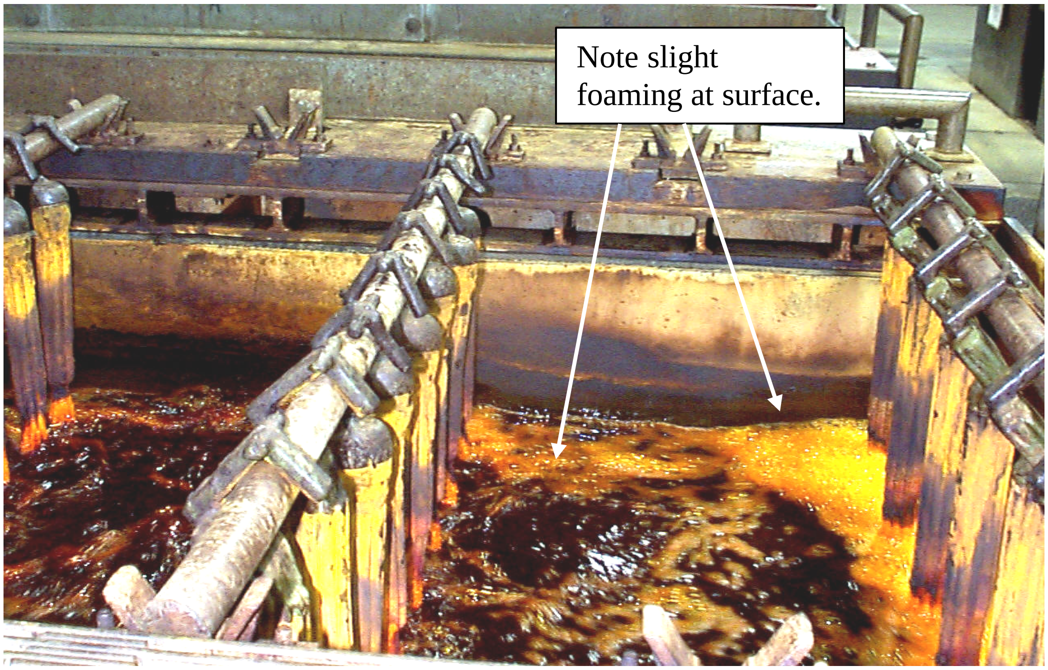


Figure 7 – TINKER, TANK 222 <u>WITH</u> FUMETROL® 140

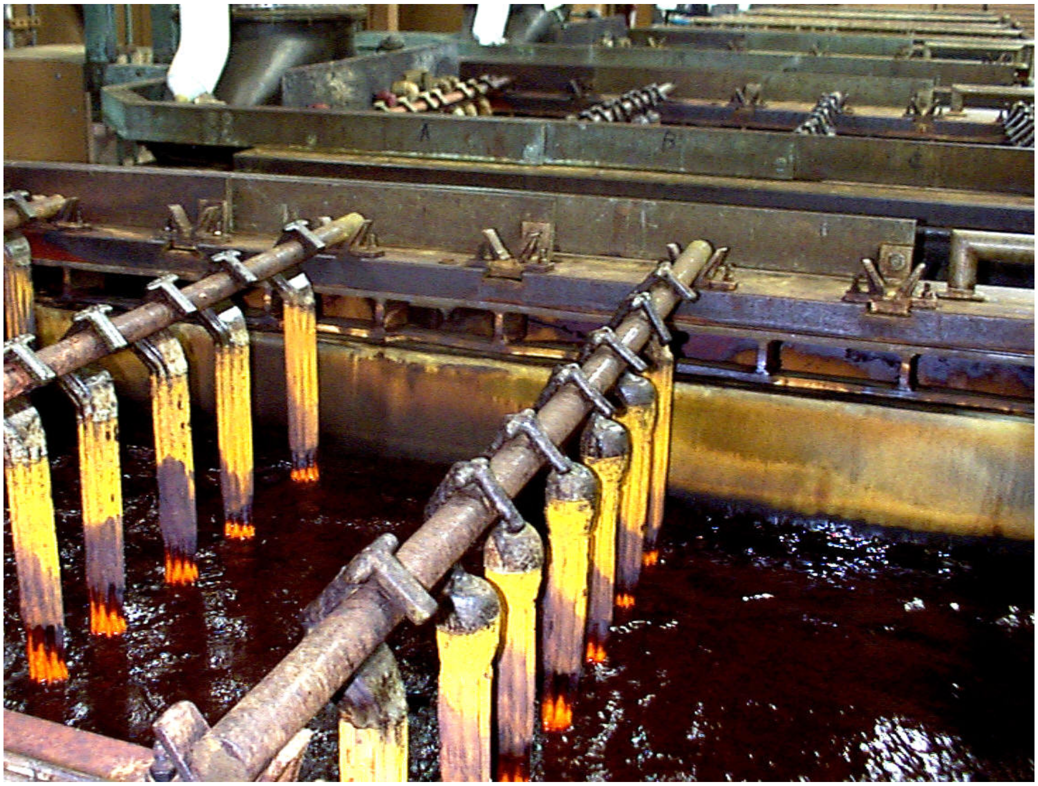


Figure 8 – TINKER, TANK 222 <u>WITHOUT</u> FUMETROL® 140

Figure 9 – NORTH ISLAND FUME SCRUBBERS

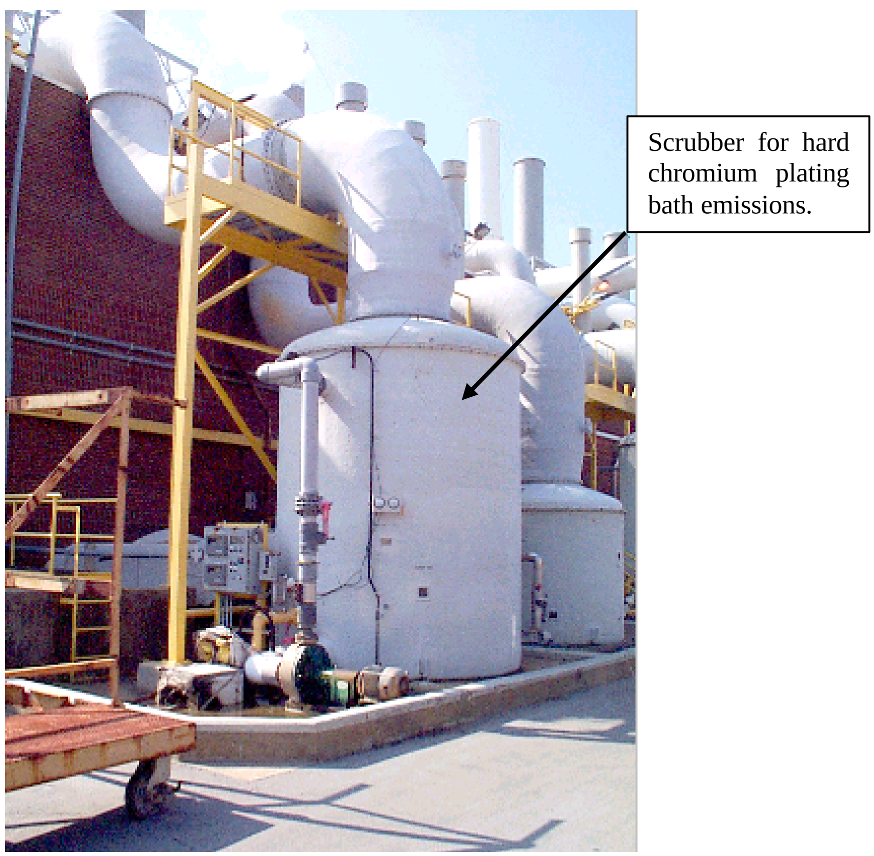


Figure 10 – CHERRY POINT FUME SCRUBBERS

APPENDIX D

TESTING AND SCHEDULING TABLES

Table 1 - Test Plan for Materials, Environmental, and Occupational Health Testing

Parameter	Sample Type	Method Number	Method Title	Method Type	Number of Samples	Controls
Test events per facility, each day, planned at Tinker and Cherry Point						
Stack Gas – Hexavalent Chromium	Time weighted average	EPA 306	*Determination of Chromium Emissions from Decorative and Hard Chrome Electroplating and Anodizing Operations*	IC/PCR	3ea 2-hr tests	One field blank
Worker Protection - Area Samples	Time weighted average	OSHA ID-215	*Hexavalent Chromium in Workplace Atmospheres*	IC w/ UV-vis detector & post column delivery system	6 samples 2 @ surface (+1-2"), 2 @ tank breathing zone (BZ), 2@ BZ >10" away from tank	1/every 5 samples submitted
One test event before and one after adding Fumetrol® 140 at Cherry Point, Tinker, and North Island						
Material Quality	Batch 1" x 4" x 0.040" coupons	Fed Spec QQ-C-320B(4)	*Chromium Plating (electrodeposited)*	Thickness Adhesion Hardness Porosity	10 samples/per test type /site (40 samples per test site)	pass/fail
Material Quality	Batch, Notched round bars	Fed Spec QQ-C-320B(4)	Sustained tensile load per ASTM F 519-97	Hydrogen Embrittle-ment	10 samples/per test type /site	pass/fail
Material Quality	Batch, Notched round bars	Fed Spec QQ-C-320B(4)	Rising step load per ASTM F 519-97 and ASTM F 1624	Hydrogen Embrittle-ment	10 samples/per test type /site	pass/ fail
Recorded during testing and Records reviewed during testing period						
Surface Tension	Grab	ASTM D1331-89	*Tensiometric*	Tensiometer	Per 40 CFR 63	
Other	Grab		*amp-hours, voltage, amps, bath temperature*			Per instrument instructions

Table 2 - Detailed Test Plan WA/FS Material Quality Testing

Test	Specimens	Method	References	Number of Samples					Test Performer
				North Island w/WA/FS	Tinker w/o WA/FS	Tinker w/ WA/FS	Cherry Point w/o WA/FS	Cherry Point w/ WAFS	
Hydrogen Embrittlement Relief	4340 notched round bars per ASTM F 519-97	Sustained load per ASTM F 519-97	QQ-C-320B	10	10	10	10	10	Pax Materials Lab
Hydrogen Embrittlement Relief	4340 notched round bars per ASTM F 519-97	Rising step load per ASTM F 519-97 and ASTM F 1624	QQ-C-320B	10	10	10	10	10	Pax Materials Lab
Thickness	4130, 1" by 4" by 0.040"	Magnetic thickness testing per ASTM B 499	QQ-C-320B section 4.5.1	10	10	10	10	10	Pax Materials Lab
Adhesion	4130, 1" by 4" by 0.040"	Mandrel bend test ASTM B 571-97 section 3.1	QQ-C-320B section 4.5.2	10	10	10	10	10	NI Materials Lab
Hardness	4130, 1" by 4" by 0.040"	Vickers hardness test per ASTM B 578	QQ-C-320B section 4.5.3	10	10	10	10	10	NI Materials Lab
Porosity	4130, 3" by 10" by 0.040"	Ferroxyl test per QQ-C-320B section 4.5.4	QQ-C-320B section 4.5.4	10	10	10	10	10	Pax Materials Lab

Table 3 - Sample Location Schedule

Sample Sites	Air Emission Tests	Start Date
NADEP Cherry Point	w/o WA/FS, & w/polyethylene shield*	11 Jul 2000
	w/o WA/FS	12 Jul 2000
	w/ WA/FS	21 Sep 2000
	w/o WA/FS	15 Nov 2000
	w/ WA/FS	16 Nov 2000
	w/ WA/FS	13 Dec 2000
	w/ WA/FS	27 Mar 2001
	w/ WA/FS	17 Apr 2001
Tinker Air Force Base	w/o WA/FS	12 Sep 2000
	w/ WA/FS	11 Oct 2000
	w/ WA/FS	8 Nov 2000
	w/ WA/FS	6 Dec 2000
	w/ WA/FS	31 Jul 2001
	w/ WA/FS	1 Aug 2001

* The first day at Cherry Point was the only time and location that the polyethylene shield was used.

APPENDIX E

FORMS AND RELATED DOCUMENTATION USED FOR THE COLLECTION OF FIELD DATA

GLOSSARY OF TERMS

A - Area of Circular Stack (ft^2)
C_p - S-Pitot Tube Correction factor (dimensionless) - assumed to be 0.84
D_n - Diameter of Probe Nozzle (inches)
D_s - Diameter of Stack (inches)
I - Percent of Isokinetic (%)
K_m - Orifice Calibration Constant (dimensionless)
M - Moisture in Gas Sample (as a gaseous volume) (ft^3)
M_p - Percent Moisture in Gas Sample (%)
MW_d - Molecular Weight of Stack Gases - dry (lb/lb-mole or g/g-mole) - assumed to be 29.0
MW_w - Molecular Weight of Stack Gases - moist (lb/lb-mole or g/g-mole)
P_a - Absolute Pressure [P_b + (P_s/13.6)] (in.Hg)
P_b - Barometric Pressure (in.Hg)
P_s - Static Pressure in Stack (in.H_2O)
Q_a - Actual Stack Volumetric Flow (acfm)
Q_d - Stack Volumetric Flow at Dry Standard Conditions (dscfm)
Q_m - Dry Gas Meter Volumetric Rate (cfm)
Q_s - Stack Volumetric Flow at Standard Conditions (scfm)
T_m - Average Dry Gas Meter Temperature (°F)
T_s - Stack Temperature (°F)
V_{dscf} - Dry Standard Volume Sampled (dscf)
V_{dscm} - Dry Standard Volume Sampled (dscm) = 2.832×10^{-2} dscf
V_{lc} - Water Collected During Sample Run (grams or ml)
V_m - Dry Gas Meter Volume Sampled (ft^3)
V_n - Velocity of Sampled Gas Inside Probe Nozzle (ft/sec)
V_s - Stack Velocity (ft/sec)
Y - Dry Gas Meter Calibration Factor (dimensionless)

? H - Pressure Drop Across Meter Orifice (in.H_2O)
? H@ - ? H Across Meter Orifice at 0.75 scfm (in.H_2O)
? P - Differential Pressure Across S-Pitot Tube (in.H_2O)
?- Sampling Run Time (minutes)

TEST PLAN - METHOD 306 STACK SAMPLING

1. At some point check barometric pressure (P_b) with local authorities, and **record**.
2. Drill holes in duct - one on side, one 90° around on bottom.
3. Confirm inside diameter of duct (D_s) (with stick, pipe, etc.).
4. Add 100 ml 0.1N NaOH to first two impingers. **Record** volumes on Water Content data sheet.
5. Add weighed 200 - 300 grams silica gel to last impinger. **Record** weight on Water Content data sheet.
6. Add ice to impinger Acold@ case.
7. Assemble sampling train.
8. **Measure** probe nozzle diameter (D_n), and plug probe w/appropriate stopper.
9. Leak test sampling train at $\geq$15 in.Hg. Must be $\leq$0.02 cfm. **Record** results on Method 306 Field Sampling data sheet.
10. Check manometer(s) to confirm levelness and zero position.
11. Mark probe with tape at appropriate distances for traverse/sampling points.
12. Perform Velocity Traverse (Use Velocity Traverse Data Sheet). Include crude cyclonic flow determination at random points.
13. **Measure** static pressure (P_s) by rotating s-pitot 90° and disconnecting one leg to manometer. Do at 3 or 4 arbitrary points.
14. **Measure** stack temperature (T_s).
15. **Measure** and **record** distance to upstream and downstream disturbances.
16. **Calculate** preliminary stack gas velocity (V_s) using 28.8 as first approximation of molecular weight of stack gases. This is used to confirm correct choice of probe nozzle size.
17. Unplug probe, insert at first traverse point, clamp in place if possible, using carpenter=s square and level.
18. Begin sampling:
    a) Turn on sampling train (be sure probe tip is unplugged!!).
    b) **Record** initial dry test meter reading, initial amperes, volts, and ampere hours.
    c) **Record** time.
    d) Adjust flow to isokinetic conditions using by-pass valve (monitor and adjust continuously).
    e) **Record** system vacuum.
    f) **Record** all parameters (dry gas meter temperatures [T_m], impinger temperature, velocity head ? P, ? H across orifice, stack temperature [T_s]) as applicable on Method 306 Field Sampling data sheet.
    g) After exactly 7-1/2 minutes of operation move probe to next traverse point, and clamp in place
    h) Repeat steps (b) - (g) until all 8 traverse points on the first axis have been completed.
    i) Close main valve (or otherwise stop sampling), and move probe to the second axis sampling port. Repeat steps (a) - (h).
19. Turn off sampling train, and remove from duct.
20. **Record** final amperage, voltage, and ampere-hours.
21. Plug probe nozzle and perform leak check. **Record** results on Method 306 Field data sheet.
22. Disassemble sampling train (**CAREFULLY**).
23. Empty impinger with silica gel onto tared balance, and quickly weigh to nearest 0.1 grams. **Record** weight on Water Content data sheet.
24. **Measure** pH of water in first impinger. Should be $\geq$8.5. If not, repeat pH measurement in second impinger.
25. **Measure** volumes of water in each of impingers 1, 2, and 3 using a graduated cylinder. **Record** volumes on Water Content data sheet. **Calculate** total grams/milliliters collected (V_{lc}). Transfer these volumes to a 1-liter polyethylene sample container. Rinse each of the 3 impingers, probe nozzle, glass probe, and interconnecting glassware and umbilicals into a graduated cylinder with a total of 200 - 300 ml of fresh 0.1N NaOH. **Record** rinsate volume and add to 1-liter polyethylene sample container (which will now contain contents of impingers 1, 2, and 3, plus all rinsate).

26. Filter contents of 1-liter container using 0.45 µm filter assembly (with N_2 pressure). Discard filter paper.
27. Place the 1-liter sample container in iced cooler (or refrigerator) for later shipment to analytical laboratory.
28. Pour about 200 ml of **fresh** 0.1 N NaOH into clean 1-liter polyethylene sample container, and place in cooler for later shipment to laboratory. This will be field blank sample. (Only one necessary per day.)
29. Clean all glassware with: soapy water, then tap water (3 times), then 0.1N NaOH (3 times), then a ≥4 hour soak in 1% HNO_3, then 0.1N NaOH (3 times), then air dry. For the umbilical cord between the probe and the impingers, skip 1% HNO_3 soak. *
30. **Calculate** Dry Standard Meter Volume (V_{dscf}), Moisture Content of Stack Gas (M and M_p), and Wet Stack Gas Molecular Weight (MW_w). Use this MW_w to recalculate Stack Velocity (V_s) for next run.
31. **Calculate** percent Isokinetic (I) to ascertain run validity.

* In most cases glassware were actually cleaned using the following protocol: strong hot alkaline rinse, deionized water rinse, 1% HNO_3 rinse, deionized water rinse, and 0.1 N NaOH rinse.

VELOCITY TRAVERSE

Facility______________________________________
Date____
Sampling Location_____________________________
Stack Inside Dimension(s)_______________________
Barometric Pressure (in.Hg)_____________________
Stack Static Pressure (in.H_2O)___________________
Operator______________________________________
S-Pitot I.D.#___________________________________
Stack Temperature (°F)__________________________
Distance to Upstream Disturbance (inches)____________
Distance to Downstream Disturbance (inches)_________

Duct/Sampling Point Drawing

Trav. Point #	**Dist. From Sample Pt. (in.)**	**? P (in. H_2O)**	**Cyclon. Flow?**	**? $P^{0.5}$**
Aver.:				

Trav. Point #	**Dist. From Sample Pt. (in.)**	**? P (in. H_2O)**	**Cyclon. Flow?**	**? $P^{0.5}$**
Aver.:				

WATER CONTENT

Facility________________________________
Sampling Location______________________
Date___________________________________
Run Number____________________________
Operator_______________________________

Impinger #	**Contents**	**Final Weight (gm)**	**Initial Weight (gm)**	**Weight Gain (col.3 - col.4)**
1	0.1N NaOH			
2	0.1N NaOH			
3	Empty			
4	Silica Gel			
TOTAL GRAMS COLLECTED (V_{lc}):				

Equipment Rinse Volume (ml):

Total Diluted Volume (ml):

METHOD 306 FIELD SAMPLING SHEET

Facility_________________	Ambient Temp. (°F)____________
Location________________	Barometric Pressure.(in.Hg)_____
Operator________________	Assumed Moisture (%)_________
Date___________________	Probe Length (inches)___________
Run Number_____________	Nozzle I.D.___________________
Sample Box No.__________	Nozzle Diameter (inches)_______
Meter Box No.___________	Initial Leak Rate (cfm)_________
Meter ? H@_____________	Final Leak Rate (cfm) _________
Meter Calib. Factor (Y)____	Static Pressure (in.H_2O)________
S-Pitot Coefficient (C_p)____	? H = _______ x ? P

Duct/Sampling Point Drawing

Trav-erse Point #	**Samp. Time (min.)**	**System vacuum (in.Hg)**	**Stack Temp. (°F) - T_s**	**Veloc. Head ("H_2O) - ? P**	**? $P^{0.5}$**	**Orifice Differ. Press. ("H_2O) - ? H**	**Dry Gas Meter Reading (ft^3) - V_m**	**Temperature at Dry Gas Meter**		**Temp.@ Last Imping. (°F)**
								Inlet (°F)	**Outlet (°F)**	
Initial Read.	0	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A
Totals										
Avgs								**T_m:**		

STACK VELOCITY (ft/sec) - V_s

$V_s = 85.49 \times C_p \times ?\, P^{0.5} \times [(T_s + 460)/(MW_w \times P_a)]^{0.5}$

$V_s = 85.49 \times C_p \times ?\, P^{0.5} \times [(T_s + 460)/(28.8^* \times P_a)]^{0.5}$

$V_s = 85.49 \times (\quad\quad) \times (\quad\quad)^{0.5} \times [((\quad\quad) + 460)/(28.8^* \times (\quad\quad))]^{0.5}$

V_s = _______________ ft/sec

* Assume for first approximation that MW_w is 28.8 (assumes 2% water by volume)

DRY STANDARD METER VOLUME (ft^3) - V_{dscf}

$V_{dscf} = V_m \times Y \times [(528/29.92) \times (P_b + (?\, H/13.6))]/(T_m + 460)$

$V_{dscf} = (\quad\quad) \times (\quad\quad) \times [17.64 \times ((\quad\quad) + ((\quad\quad)/13.6))]/[(\quad\quad) + 460]$

V_{dscf} = _______________ dscf

MOISTURE CONTENT OF STACK GAS (as a gas) (ft^3) - M

$M = 8.94 \times 10^{-5}\ ft^3/\text{gram} \times \text{Standard Temperature} \times V_{lc}$

$M = 8.94 \times 10^{-5} \times 528 \times V_{lc}$

$M = 0.047 \times (\quad\quad)$

M = _______________ft^3

MOISTURE CONTENT OF STACK GAS (as a gas) (%) - M_p

$M_p = 100 \text{ x } M / (M + V_{dscf})$

$M_p = 100 \text{ x } (\quad\quad) / [(\quad\quad) + (\quad\quad)]$

M_p = ________________ %

WET GAS MOLECULAR WEIGHT (lb/lb-mole) - MW_w

(Assume MW_d = 29.0 per Method 2, section 3.6)

$MW_w = [29.0 \text{ x } (1 - (M_p/100))] + (18 \text{ x } M_p/100)$

$MW_w = [29.0 \text{ x } (1 - ((\quad\quad)/100))] + [0.18 \text{ x } (\quad\quad)]$

MW_w = __________________ lb/lb-mole (or g/g-mole)

AREA OF CIRCULAR STACK (ft^2) - A

$A = D_s^2 \text{ x } 5.454\text{x}10^{-3}$

$A = (\quad\quad)^2 \text{ x } 5.454\text{x}10^{-3}$

A = ________________ ft^2

ACTUAL STACK VOLUMETRIC FLOW RATE (acfm) - Q_a

$Q_a = V_s \text{ x } A \text{ x } 60$

$Q_a = (\quad\quad) \text{ x } (\quad\quad) \text{ x } 60$

Q_a = ____________________ acfm

STANDARD STACK VOLUMETRIC RATE (scfm) - Q_s

$Q_s = Q_a$ x (528/29.92) x $[P_a/(T_s + 460)]$

Q_s = (   ) x 17.65 x [(   )/((   ) + 460)]

Q_s = ____________________ scfm

DRY STANDARD STACK VOLUMETRIC RATE (dscfm) - Q_d

$Q_d = Q_s$ x $(1 - (M_p/100))$

Q_d = (   ) x [1 - ((   )/100)]

Q_d = ____________________ dscfm

ISOKINETIC DETERMINATION (%) - I

$$I = \frac{100 \text{ x } (T_s + 460) \text{ x } [\{2.669\text{x}10^{-3} \text{ x } V_{lc}\} + \{[(V_m \text{ x } Y)/(T_m + 460)] \text{ x } (P_b + (? H/13.6))\}]}{60 \text{ x } ? \text{ x } V_s \text{ x } P_a \text{ x } (D_n^2 \text{ x } 5.45\text{x}10^{-3})}$$

$$I = \frac{100 \text{ x } ((\quad) + 460) \text{ x } [\{2.669\text{x}10^{-3} \text{ x } (\quad)\} + \{[((\quad) \text{ x } (\quad))/((\quad) + 460)] \text{ x } ((\quad) + ((\quad)/13.6))\}]}{0.327 \text{ x } (\quad) \text{ x } (\quad) \text{ x } (\quad) \text{ x } (\quad)^2}$$

I = ______________________ %

?H VERSUS ?P RELATIONSHIP FOR QUICK ISOKINETIC ADJUSTMENT

$? H = \{846.72 \text{ x } D_n^4 \text{ x } ? H_@ \text{ x } C_p^2 \text{ x } (1 - (M_p/100))^2 \text{ x } (MW_d/MW_w) \text{ x } ((460 + T_m)/(460 + T_s)) \text{ x } (P_a/(P_b + ? H/13.6))\}\text{x}? P$

If $C_p = 0.84$, then:

$? H = \{597.45 \text{ x } D_n^4 \text{ x } ? H_@ \text{ x } (1 - (M_p/100))^2 \text{ x } (MW_d/MW_w) \text{ x } ((460 + T_m)/(460 + T_s)) \text{ x } (P_a/(P_b + ? H/13.6))\} \text{ x } ? P$

If $M_p = 2.0$ %, $MW_d = 29.0$, and $MW_w = 28.8$, then:

$? H = \{589.56 \text{ x } D_n^4 \text{ x } ? H_@ \text{ x } (460 + T_m)/(460 + T_s) \text{ x } (P_a/(P_b + ? H/13.6))\} \text{ x } ? P$

$D_n =$

$D_n^4 =$

$M_p =$

$(1 - (M_p/100))^2 =$

$? H_@ =$

$MW_w =$ $MW_d/MW_w =$

$T_m =$ $T_s =$

$(460 + T_m)/(460 + T_s) =$

$P_b =$ $P_s =$

$P_a = (P_b + (P_s/13.6)) =$

$? H_{(assumed)} =$ $(P_b + (? H_{(assumed)}/13.6)) =$ $P_a/\{P_b + (? H_{(assumed)}/13.6)\} =$

$? H = ($ $) \text{ x } ? P$

To: Fax:	From: POC: Phone:

INDUSTRIAL HYGIENE SINGLE STRESSOR AIR SAMPLE SURVEY FORM

IH UIC:______________________ Activity:____ UIC:_________________________ Date:

Fax:

Building/Location:____Shop/Code:________________________

Product Used:____

Ventilation: ____ Meets Specs: ____________ Used: _________

Exposure during the unsampled period is: Same as the sampled period Zero Other _________________

Shift:	1. Day	Frequency of Operation	1. Daily	2. 2-3/wk	3. Weekly	4. 2-3/mo	Duration of Operation	1. 0-15 min	2. 15-30 min	3. 30-60 min	Y/N 4. 1-2 hr
2. Eve.	3. Night		5. Monthly	6. 2-3/yr	7. Yearly	8. Special		5. 2-4 hr	6. 4-6 hr	7. 6-8 hr	8. >8 hr

M or C P or A	M C 1 P A	M C 2 P A	M C 3 P A	M C 4 P A	M C 5 P A
Employee Name:					
SSN/Badge #					
Task					
Worksite					
Job Title					
Operation					
Code					
Respirator					
Code					
PPE					
Code(s)					
Stressor					
CAS #					
Sample #					
Laboratory #					
Sample Duration					
Flow Rate (minutes)					
Volume (liters per minute)					
Results (liters)					
Concentration					
8-hr TWA					

Date Received: __________________ Analytical Method: _____________ LOD: ______

Analysis Performed By: ______________________ Date Analyzed: _________________
Analysis Reviewed By: _______________________Date Reported: _________________

Comments:

NEHC 5100/14
(REV 3/99)

(Mfg) (Model) (Serial #)

Calibrator: ____ Pre Cal Date: ____________________

Calibrated By: ____ Post Cal Date: ____________________

	1	2	3	4	5
Pump Mfg					
Pump Model					
Pump Type					
Pump Serial #					
Pre Cal Flow Rate					
Post Cal Flow rate					
Lower Flow Rate					
Field ID #					
Media					
Lot/Tube #					
Expiration Date					
Time Off					
Time On					
Pump Check(s)					

Calculations:

IHT/WPM: ____________________ Date: ________ IH: _____________________ Date: ___________

PRIVACY ACT STATEMENT: The Privacy Act of 1974 requires that federal agencies inform individuals about certain facts they are requested to provide for inclusion into government records, such as this industrial hygiene record. These records, as appropriate, may be furnished to agencies of the Federal, State, or local government for legal, regulatory or administrative purposes. Disclosure of the requested information is voluntary, however, if not provided, acceptance of the submitted record may be denied.

Signature	Signature	Signature	Signature	Signature
Date	Date	Date	Date	Date

Sample Chain of Custody Form for Stack Emission Samples

Versar INC.

CHAIN OF CUSTODY RECORD

PROJECT NO.:

PROJECT NAME: CHERRY POINT - HARD CHROME PLATING

INDUSTRIAL HYGIENE SAMPLE: Y / N (N circled)

SAMPLERS: (Signature) [signature]

(Printed) STEPHEN M. SCHWARTZ

PARAMETERS

FIELD SAMPLE NUMBER	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS	HEXAVALENT CHROME							REMARKS
1	7/12	6:40P		✓	TEST 1	1	✓							
2	↓	↓		✓	TEST 2	1	✓							
3				✓	TEST 3	1	✓							
4				✓	TEST 4	1	✓							
5				✓	TEST 5	1	✓							
6				✓	TEST 6	1	✓							
7				✓	TEST 7	1	✓							

Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
[signature]	7/12/00 6:45P	Kathleen M Paulson	Kathleen M Paulson	7/13/00 12:43	[signature] 7-13-00 12:43
(Printed) STEPHEN M. SCHWARTZ		(Printed) Kathleen M Paulson	(Printed)		(Printed)

Relinquished by: (Signature)	Date / Time	Received for Laboratory by: (Signature)	Date / Time	Remarks
				Do Cr+6 USING IC/PCR & VISIBLE WAVELENGTH DETECTOR
(Printed)		(Printed)		

FY00 Test Coupon Matrix Log		Sample Logging Matrix NAVAIR Patuxent River Laboratory		
Matrix Number		**Project Name**	**Originator**	**Date**
0	1	Trivalent Chromium Pretreatment Application and Test	Craig Matzdorf	10/13/1999
0	2	TCP10M Application and Test	Craig Matzdorf	11/22/1999
0	3	TCP10 Paint Adhesion Validation	Craig Matzdorf	12/14/1999
0	4	TCP10M Spray Corrosion Performance Validation	Craig Matzdorf	3/2/2000
0	5	TCP10 Surface Tension Evaluation	Craig Matzdorf	1/5/2000
0	6	TCP Surface Tension(Painted) Evaluation	Craig Matzdorf	3/7/2000
0	7	TCP Timing/Use Evaluation	Craig Matzdorf	7/6/2000
0	8	F-18 (Painted) Corrosion Test	Craig Matzdorf	6-15-2000
0	9			
0	10			
0	11			
0	12			
0	13			
0	14			
0	15			
0	16			
0	17			
0	18			
0	19			
0	20			

SAMPLE Tracking Record for NAVAIR Patuxent River Laboratory														
FY00 Matrix 03														
TCP10 Paint Adhesion Validation (Note: This is not the WA/FS test)														
7075-T6								2024-T3						
Panel	SPT	23377	85582	85582N	Test	Pretreat		Panel	SPT	23377	85582	85582N	Test	Pretreat
7-1	X				1D WTA	Accelagold-S		2-1	X				1D WTA	Accelagold-S
7-2	X				4D WTA	Accelagold-S		2-2	X				4D WTA	Accelagold-S
7-3	X				7D WTA	Accelagold-S		2-3	X				7D WTA	Accelagold-S
7-4		X			1D WTA	Accelagold-S		2-4		X			1D WTA	Accelagold-S
7-5		X			4D WTA	Accelagold-S		2-5		X			4D WTA	Accelagold-S
7-6		X			7D WTA	Accelagold-S		2-6		X			7D WTA	Accelagold-S
7-7			X		1D WTA	Accelagold-S		2-7			X		1D WTA	Accelagold-S
7-8			X		4D WTA	Accelagold-S		2-8			X		4D WTA	Accelagold-S
7-9			X		7D WTA	Accelagold-S		2-9			X		7D WTA	Accelagold-S
7-10				X	1D WTA	Accelagold-S		2-10				X	1D WTA	Accelagold-S
7-11				X	4D WTA	Accelagold-S		2-11				X	4D WTA	Accelagold-S
7-12				X	7D WTA	Accelagold-S		2-12				X	7D WTA	Accelagold-S
7-13	X				1D WTA	Alodine 1200S-W		2-13	X				1D WTA	Alodine 1200S-W
7-14	X				4D WTA	Alodine 1200S-W		2-14	X				4D WTA	Alodine 1200S-W
7-15	X				7D WTA	Alodine 1200S-W		2-15	X				7D WTA	Alodine 1200S-W
7-16		X			1D WTA	Alodine 1200S-W		2-16		X			1D WTA	Alodine 1200S-W
7-17		X			4D WTA	Alodine 1200S-W		2-17		X			4D WTA	Alodine 1200S-W
7-18		X			7D WTA	Alodine 1200S-W		2-18		X			7D WTA	Alodine 1200S-W
7-19			X		1D WTA	Alodine 1200S-W		2-19			X		1D WTA	Alodine 1200S-W
7-20			X		4D WTA	Alodine 1200S-W		2-20			X		4D WTA	Alodine 1200S-W
7-21			X		7D WTA	Alodine 1200S-W		2-21			X		7D WTA	Alodine 1200S-W
7-22				X	1D WTA	Alodine 1200S-W		2-22				X	1D WTA	Alodine 1200S-W
7-23				X	4D WTA	Alodine 1200S-W		2-23				X	4D WTA	Alodine 1200S-W
7-24				X	7D WTA	Alodine 1200S-W		2-24				X	7D WTA	Alodine 1200S-W
7-25	X				1D WTA	Alodine 1200S-I		2-25	X				1D WTA	Alodine 1200S-I
7-26	X				4D WTA	Alodine 1200S-I		2-26	X				4D WTA	Alodine 1200S-I
7-27	X				7D WTA	Alodine 1200S-I		2-27	X				7D WTA	Alodine 1200S-I
7-28		X			1D WTA	Alodine 1200S-I		2-28		X			1D WTA	Alodine 1200S-I
7-29		X			4D WTA	Alodine 1200S-I		2-29		X			4D WTA	Alodine 1200S-I
7-30		X			7D WTA	Alodine 1200S-I		2-30		X			7D WTA	Alodine 1200S-I
7-31			X		1D WTA	Alodine 1200S-I		2-31			X		1D WTA	Alodine 1200S-I
7-32			X		4D WTA	Alodine 1200S-I		2-32			X		4D WTA	Alodine 1200S-I
7-33			X		7D WTA	Alodine 1200S-I		2-33			X		7D WTA	Alodine 1200S-I
7-34				X	1D WTA	Alodine 1200S-I		2-34				X	1D WTA	Alodine 1200S-I
7-35				X	4D WTA	Alodine 1200S-I		2-35				X	4D WTA	Alodine 1200S-I

*SAMPLE MATERIALS LAB REPORT #**TR-YYMMDD-PROG-B-ABC-1****

Prepared By:

Prepared For (Customer):

Location: Inorganic Coatings Laboratory, Aerospace Materials Division, Patuxent River, MD

Purpose:

Issues:

Test Method and Sampling Procedures:

Subcontracted Efforts:

Environmental Conditions:

Conclusion and Results:

Lab Manager Approval & Date:

**** # is derived from below:***

YYMMDD = Date of Report (e.g.: 990129 for 29 Jan 1999)

PROG = Program (If Applicable. If not, omit)

B = Branch (0 for 434, 1 for 4341, 2 for 4342, & 3 for 4343)

ABC = Individuals Initials

1 = sequential # of related report

APPENDIX F

FATIGUE TEST METHODOLOGY

and

SPECIMEN SPECIFICATIONS

A Comparison of Chrome Plating Processes on the Axial Fatigue Behavior of Aermet 100, 300M, and 13-8PH Steels

NAVAIR
Naval Air Warfare Center – Aircraft Division
Aerospace Materials Division
Metals, Ceramics & NDE Branch
Patuxent River, Maryland 20670

March 27, 2003

Customer

Craig Matzdorf
Materials Engineer
NAWC-AD, Code 4.3.4.1
Building 2188, M/S 5
48066 Shaw Road
Patuxent River, Maryland 20670
Phone: 301-342-9372
E-mail: matzdorfc@navair.navy.mil

Project Engineer

Michael J. Leap
Materials Engineer & Technical Manager
Mechanical Properties Laboratory
NAWC-AD, Code 4.3.4.2
Building 2188, M/S 5
48066 Shaw Road
Patuxent River, Maryland 20670
Phone: 301-342-8022
Facsimile: 301-342-8024
E-mail: leapmj@navair.navy.mil

Michael J. Leap

Work Performed by:

J. Bilko
H. C. Sanders
R. E. Taylor

Investigation MT1089
(Distribution Limited to Codes 4.3.4.1 and 4.3.4.2)

Summary

Axial fatigue tests were conducted to evaluate the effects of chrome plating processes on the fatigue resistance of Aermet 100, 300M, and 13-8PH steels. Uncoated specimens, which provide a baseline measure of fatigue resistance for each material, are compared to specimens chrome plated with a standard process and specimens chrome plated with a fume suppressant. The high cycle fatigue behavior of each material was evaluated at stress ratios of –1 and 0.1 with a 30 Hz sinusoidal loading waveform while the low cycle fatigue behavior was evaluated at strain ratios of –1 and 0.1 with a 0.4 Hz triangular loading waveform. The customer specified the maximum stress and strain values for the different steels and stress/strain ratios.

Conclusions

1. Uncoated specimens of the three steels qualitatively exhibit better fatigue resistance than specimens chrome plated with either a standard process or a process employing a fume suppressant.

2. Specimens chrome plated with a process that employs a fume suppressant exhibit longer fatigue lives than specimens chrome plated with a standard process for a majority of the steels and test conditions. **However, since a very limited number of specimens were tested for each material and test condition, statistical comparisons between data sets should only be treated as rough qualitative indications of the effects of chrome plating process on fatigue life.**

Background

The test program was initiated to evaluate the effects of utilizing a fume suppressant during chrome plating on the fatigue behavior of plated Aermet 100, 300M, and 13-8PH steel specimens subjected to different load ratios and loading severities. The customer supplied uncoated specimens, specimens plated with a standard process, and specimens plated with a process that incorporates a fume suppressant. The customer also specified the loading parameters for each series of tests and, subsequent to testing, verbally requested a statistical analysis of the fatigue life data.

The purpose of this report is to document the results of the testing program and provide a summary of the fatigue life data.

Procedure

Axial fatigue test parameters for the three steels are summarized in Table 1. The tests were conducted on straight-gaged specimens with a 0.25 in. diameter and a 0.75 in. gage length. High cycle fatigue (HCF) tests were conducted at stress ratios of –1 and 0.1 on servohydraulic test systems operating in load control with a 30 Hz sinusoidal loading waveform. Run-out is defined as specimen survival at 10^7 cycles for the HCF tests. Low cycle fatigue (LCF) tests were conducted at strain ratios of –1 and 0.1 on servohydraulic test systems operating in strain control with a 0.4 Hz triangular loading waveform. Strain control during LCF testing was achieved with a 0.5 in. extensometer mounted over the center of each specimen. LCF specimens that survived 10^4 cycles were removed from test.

Based on a request by the customer, a statistical analysis of the fatigue life data for each steel and loading history was conducted using a commercial software package.[1] Fatigue life data were evaluated in terms of both normal and Weibull distributions with a maximum likelihood estimation procedure. LCF specimens that survived 10^4 cycles and specimens that failed outside the gage section were treated as suspended tests in the analysis.

Results and Discussion

Fatigue data for the Aermet 100, 300M, and 13-8PH steels are tabulated in Appendix A, B, and C, respectively. A summary of statistical parameters for normal distribution and Weibull distribution representations of the fatigue data is provided in Tables 2-4 and Tables 5-7, respectively. With the exception of Aermet 100 specimens tested at 110 ksi and R = -1, the selected stress levels for HCF tests on uncoated specimens are less than or very near the endurance limit, σ_{END}, for all combinations of material and stress ratio. The strain levels selected for the LCF tests also are lower than the strains corresponding to a fatigue limit of 10^4 cycles, ε_{FL}, in four of six combinations of material and strain ratio. Thus, quantitative comparisons of the degradation in the LCF and HCF life of the steels resulting from either chrome plating process are not possible in a majority of cases, although these data qualitatively suggest that the fatigue life of the uncoated specimens is greater than the fatigue life of specimens plated with either process when tested at equivalent conditions. Consistent with this observation, the fatigue lives of chrome plated specimens are significantly less than the fatigue life of the corre-

[1]Weibull++, version 6 - Trademark of ReliaSoft Corporation.

sponding uncoated specimens for the three conditions in which the uncoated specimens exhibit finite life, Tables 2 and 3.

Fatigue life comparisons for specimens chrome plated with a standard process and a process employing a fume suppressant are summarized in Table 8. The data for both normal distribution and Weibull distribution representations of the fatigue data suggest that the fatigue life of specimens chrome plated with a fume suppressant is greater than the fatigue life of specimens chrome plated with a standard process for the 300M steel, 13-8PH stainless steel, and HCF specimens of the Aermet 100 steel. Conversely, Aermet 100 specimens plated with the two processes exhibit similar LCF fatigue lives.

While a majority of these data indicate significant differences in fatigue life, it must be recognized that the statistical basis for each data set is not sufficient to provide reliable quantitative estimates of the distribution parameters for each material and testing condition. Therefore, the distribution parameters, Tables 2-7, and the statistical comparisons, Table 8, should only be treated as rough indicators of fatigue life and differences in fatigue life. A great deal more data (i.e., 15-20 specimens per condition) obviously would be required to provide reliable estimates of the distribution parameters for each material and testing condition.

Table 1: Summary of Axial Fatigue Test Paramaters

MATERIAL	HIGH CYCLE FATIGUE TESTS				LOW CYCLE FATIGUE TESTS			
	STRESS RATIO, R	MAXIMUM STRESS (ksi)	TEST FREQUENCY (Hz)	APPLIED LOADING WAVEFORM	STRAIN RATIO, R	MAXIMUM STRAIN	TEST FREQUENCY (Hz)	APPLIED LOADING WAVEFORM
AERMET 100 STEEL	-1	110	30	SINUSOIDAL	-1	0.0066	0.4	TRIANGULAR
	0.1	160	30	SINUSOIDAL	0.1	0.0140	0.4	TRIANGULAR
300M STEEL	-1	95	30	SINUSOIDAL	-1	0.0057	0.4	TRIANGULAR
	0.1	135	30	SINUSOIDAL	0.1	0.0110	0.4	TRIANGULAR
13-8PH STAINLESS STEEL	-1	85	30	SINUSOIDAL	-1	0.0054	0.4	TRIANGULAR
	0.1	150	30	SINUSOIDAL	0.1	0.0080	0.4	TRIANGULAR

Table 2: Normal Distribution Parameters for Aermet 100 Steel

COATING CONDITION	TEST TYPE (LCF OR HCF)	STRESS OR STRAIN RATIO, R	NUMBER OF SPECIMENS	STATISTICAL BASIS	FATIGUE LIFE, MEAN ± STD. DEVIATION (CYCLES)	LOWER/UPPER 95% CONFIDENCE LIMITS (CYCLES)	LOWER/UPPER 99% CONFIDENCE LIMITS (CYCLES)	COMMENTS
UNCOATED	HCF	-1	8	3	5452500 ± 4750500	7508700/10154000	. . ./11631000	1 INVALID TEST, 1 SUSPENDED TEST, AND 3 RUN-OUTS.
	HCF	0.1	5	. . .	$\sigma \approx \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	4 RUN-OUTS AND 1 SPECIMEN FAILURE AT 432088 CYCLES.
EXTRA HARD CHROME	HCF	-1	4	4	13066 ± 1186	11903/14228	11538/14593	
	HCF	0.1	4	3	8583 ± 288	8257/8909	8155/9012	1 TEST (N = 44090 CYCLES) TREATED AS AN OUTLIER.
EXTRA HARD CHROME WITH FUME SUPPRESSANT	HCF	-1	4	4	17468 ± 374	17101/17834	16986/17949	
	HCF	0.1	4	2	10937 ± 96	10817/11057	10779/11095	2 SUSPENDED TESTS.
UNCOATED	LCF	-1	6	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	5 SUSPENDED TESTS AND 1 SPECIMEN FAILURE AT 8728 CYCLES (INVALID TEST).
	LCF	0.1	4	4	5818 ± 1043	4795/6840	4474/7161	
EXTRA HARD CHROME	LCF	-1	4	2	3981 ± 1724	1865/6097	1200/6762	2 SUSPENDED TESTS.
	LCF	0.1	4	4	2582 ± 636	1958/3206	1762/3402	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	LCF	-1	4	2	. . .	. . .	. . .	2 SUSPENDED TESTS. NO CONVERGENCE OF DATA TO A SOLUTION.
	LCF	0.1	4	4	2569 ± 387	2189/2949	2070/3068	

Table 3: Normal Distribution Parameters for 300M Steel

COATING CONDITION	TEST TYPE (LCF OR HCF)	STRESS OR STRAIN RATIO, R	NUMBER OF SPECIMENS	STATISTICAL BASIS	FATIGUE LIFE, MEAN ± STD. DEVIATION (CYCLES)	LOWER/UPPER 95% CONFIDENCE LIMITS (CYCLES)	LOWER/UPPER 99% CONFIDENCE LIMITS (CYCLES)	COMMENTS
UNCOATED	HCF	-1	5	. . .	$\sigma \approx \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	4 RUN-OUTS AND 1 SPECIMEN FAILURE AT 215087 CYCLES.
	HCF	0.1	4	. . .	$\sigma \leq \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	4 RUN-OUTS.
EXTRA HARD CHROME	HCF	-1	4	4	24556 ± 847	23725/25386	23464/25647	
	HCF	0.1	4	4	18410 ± 3180	15294/21527	14314/22506	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	HCF	-1	5	4	26028 ± 704	25374/26682	25169/26887	1 SUSPENDED TEST.
	HCF	0.1	3	3	20260 ± 1593	18457/22063	17891/22629	
UNCOATED	LCF	-1	4	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	4 SUSPENDED TESTS.
	LCF	0.1	4	3	7987 ± 1156	6678/9296	6267/9707	DATA RECORD FOR ONE SPECIMEN LOST.
EXTRA HARD CHROME	LCF	-1	4	4	3055 ± 1193	1885/4225	1518/4593	
	LCF	0.1	5	4	3018 ± 327	2698/3338	2598/3439	1 SUSPENDED TEST.
EXTRA HARD CHROME WITH FUME SUPPRESSANT	LCF	-1	4	4	5284 ± 2141	3185/7383	2526/8042	
	LCF	0.1	4	4	3876 ± 438	3446/4306	3311/4441	

Table 4: Normal Distribution Parameters for 13-8PH Stainless Steel

COATING CONDITION	TEST TYPE (LCF OR HCF)	STRESS OR STRAIN RATIO, R	NUMBER OF SPECIMENS	STATISTICAL BASIS	FATIGUE LIFE, MEAN ± STD. DEVIATION (CYCLES)	LOWER/UPPER 95% CONFIDENCE LIMITS (CYCLES)	LOWER/UPPER 99% CONFIDENCE LIMITS (CYCLES)	COMMENTS
UNCOATED	HCF	-1	4	. . .	$\sigma \leq \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	4 RUN-OUTS.
	HCF	0.1	4	. . .	$\sigma \leq \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	4 RUN-OUTS.
EXTRA HARD CHROME	HCF	-1	4	4	38036 ± 2293	35789/40284	35082/40990	
	HCF	0.1	4	4	16644 ± 1613	15063/18225	14567/18721	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	HCF	-1	4	4	60184 ± 3007	57237/63132	56311/64058	
	HCF	0.1	4	4	22071 ± 2075	20038/24105	19399/24744	
UNCOATED	LCF	-1	4	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	4 SUSPENDED TESTS.
	LCF	0.1	4	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	4 SUSPENDED TESTS.
EXTRA HARD CHROME	LCF	-1	5	3	8724 ± 1707	7022/10427	6487/10962	2 SUSPENDED TESTS.
	LCF	0.1	4	4	6711 ± 2974	3796/9626	2880/10542	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	LCF	-1	4	. . .	. . .	. . .	. . .	4 INVALID TESTS.
	LCF	0.1	4	2	9846 ± 774	8947/10745	8664/11028	2 SUSPENDED TESTS.

Table 5: Weibull Distribution Parameters for Aermet 100 Steel

COATING CONDITION	TEST TYPE (LCF OR HCF)	STRESS OR STRAIN RATIO, R	NUMBER OF SPECIMENS	STATISTICAL BASIS	MEDIAN FATIGUE LIFE, L_{50} (CYCLES)	CHARACTERISTIC FATIGUE LIFE, L_C (CYCLES)	WEIBULL SLOPE, m	LOWER/UPPER 95% CONFIDENCE LIMITS (CYCLES)	COMMENTS
UNCOATED	HCF	-1	8	3	4550800	7406600	0.75	994610/20822000	1 INVALID TEST, 1 SUSPENDED TEST, AND 3 RUN-OUTS.
	HCF	0.1	5	. . .	$\sigma \approx \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	. . .	4 RUN-OUTS AND 1 SPECIMEN FAILURE AT 432088 CYCLES.
EXTRA HARD CHROME	HCF	-1	4	4	13205	13545	14.4	12182/14313	
	HCF	0.1	4	3	. . .	. . .	m > 20	. . .	1 TEST (N = 44090 CYCLES) TREATED AS AN OUTLIER. WEIBULL DISTRIBUTION NOT APPROPRIATE FOR DATA SET.
EXTRA HARD CHROME WITH FUME SUPPRESSANT	HCF	-1	4	4	. . .	. . .	m > 20	. . .	WEIBULL DISTRIBUTION NOT APPROPRIATE FOR DATA SET (m > 20).
	HCF	0.1	4	2	. . .	. . .	m > 20	. . .	2 SUSPENDED TESTS. WEIBULL DISTRIBUTION NOT APPROPRIATE FOR DATA SET (m > 20).
UNCOATED	LCF	-1	6	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	. . .	5 SUSPENDED TESTS AND 1 SPECIMEN FAILURE AT 8728 CYCLES (INVALID TEST).
	LCF	0.1	4	4	5939	6177	9.32	5251/6716	
EXTRA HARD CHROME	LCF	-1	4	2	3922	4574	2.38	2191/7020	2 SUSPENDED TESTS.
	LCF	0.1	4	4	2619	2807	5.27	2101/3263	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	LCF	-1	4	2	3953	4073	12.2	3468/4505	2 SUSPENDED TESTS.
	LCF	0.1	4	4	2612	2710	9.89	2324/2935	

Table 6: Weibull Distribution Parameters for 300M Steel

COATING CONDITION	TEST TYPE (LCF OR HCF)	STRESS OR STRAIN RATIO, R	NUMBER OF SPECIMENS	STATISTICAL BASIS	MEDIAN FATIGUE LIFE, L_{50} (CYCLES)	CHARACTERISTIC FATIGUE LIFE, L_C (CYCLES)	WEIBULL SLOPE, m	LOWER/UPPER 95% CONFIDENCE LIMITS (CYCLES)	COMMENTS
UNCOATED	HCF	-1	5	. . .	$\sigma \approx \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	. . .	4 RUN-OUTS AND 1 SPECIMEN FAILURE AT 215087 CYCLES.
	HCF	0.1	4	. . .	$\sigma \leq \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	. . .	4 RUN-OUTS.
EXTRA HARD CHROME	HCF	-1	4	4	. . .	. . .	m > 20	. . .	WEIBULL DISTRIBUTION NOT APPROPRIATE FOR DATA SET (m > 20).
	HCF	0.1	4	4	18807	19495	10.2	16811/21040	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	HCF	-1	5	4	. . .	. . .	m > 20	. . .	1 SUSPENDED TEST. WEIBULL DISTRIBUTION NOT APPROPRIATE FOR DATA SET (m > 20).
	HCF	0.1	3	3	20437	20887	16.8	18870/22134	
UNCOATED	LCF	-1	4	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	. . .	4 SUSPENDED TESTS.
	LCF	0.1	4	3	8124	8390	11.4	7222/9138	DATA RECORD FOR ONE SPECIMEN LOST.
EXTRA HARD CHROME	LCF	-1	4	4	3071	3422	3.39	2177/4333	
	LCF	0.1	5	4	3056	3169	10.1	2728/3425	1 SUSPENDED TEST.
EXTRA HARD CHROME WITH FUME SUPPRESSANT	LCF	-1	4	4	5244	5930	2.98	3551/7745	
	LCF	0.1	4	4	3919	4053	10.9	3524/4359	

Table 7: Weibull Distribution Parameters for 13-8PH Stainless Steel

COATING CONDITION	TEST TYPE (LCF OR HCF)	STRESS OR STRAIN RATIO, R	NUMBER OF SPECIMENS	STATISTICAL BASIS	MEDIAN FATIGUE LIFE, L_{50} (CYCLES)	CHARACTERISTIC FATIGUE LIFE, L_C (CYCLES)	WEIBULL SLOPE, m	LOWER/UPPER 95% CONFIDENCE LIMITS (CYCLES)	COMMENTS
UNCOATED	HCF	-1	4	. . .	$\sigma \leq \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	. . .	4 RUN-OUTS.
	HCF	0.1	4	. . .	$\sigma \leq \sigma_{END}$ (REFER TO REPORT)	. . .	. . .	. . .	4 RUN-OUTS.
EXTRA HARD CHROME	HCF	-1	4	4	38274	39043	18.4	35936/40765	
	HCF	0.1	4	4	16849	17286	14.3	15531/18279	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	HCF	-1	4	4	. . .	. . .	m > 20	. . .	WEIBULL DISTRIBUTION NOT APPROPRIATE FOR DATA SET (m > 20).
	HCF	0.1	4	4	22253	22959	11.7	20151/24573	
UNCOATED	LCF	-1	4	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	. . .	4 SUSPENDED TESTS.
	LCF	0.1	4	. . .	$\varepsilon \leq \varepsilon_{FL}$ (REFER TO REPORT)	. . .	. . .	. . .	4 SUSPENDED TESTS.
EXTRA HARD CHROME	LCF	-1	5	3	8817	9399	5.74	7223/10764	2 SUSPENDED TESTS.
	LCF	0.1	4	4	6678	7499	3.16	4654/9584	
EXTRA HARD CHROME WITH FUME SUPPRESSANT	LCF	-1	4	. . .	. . .	. . .	. . .	. . .	4 INVALID TESTS.
	LCF	0.1	4	2	9854	10056	18.1	9123/10644	2 SUSPENDED TESTS.

Table 8: Summary of Statistical Comparisons

MATERIAL	CONDITION 1	CONDITION 2	TEST TYPE (LCF OR HCF)	NORMAL DISTRIBUTION REPRESENTATION OF DATA		WEIBULL DISTRIBUTION REPRESENTATION OF DATA	
				COMPARISON OF MEAN LIVES	PROBABILITY OF DIFFERENCE IN MEAN LIVES	COMPARISON OF MEDIAN LIVES	PROBABILITY OF DIFFERENCE IN MEDIAN LIVES
AERMET 100 STEEL	EHC R = -1	EHC/WFS R = -1	HCF	CONDITION 1 < CONDITION 2	>0.99	NO COMPARISON POSSIBLE	
	EHC R = 0.1	EHC/WFS R = 0.1	HCF	CONDITION 1 < CONDITION 2	>0.99	NO COMPARISON POSSIBLE	
AERMET 100 STEEL	EHC R = -1	EHC/WFS R = -1	LCF	NO COMPARISON POSSIBLE		CONDITION 1 < CONDITION 2	0.50
	EHC R = 0.1	EHC/WFS R = 0.1	LCF	CONDITION 1 > CONDITION 2	0.51	CONDITION 1 > CONDITION 2	0.52
300M STEEL	EHC R = -1	EHC/WFS R = -1	HCF	CONDITION 1 < CONDITION 2	0.91	NO COMPARISON POSSIBLE	
	EHC R = 0.1	EHC/WFS R = 0.1	HCF	CONDITION 1 < CONDITION 2	0.70	CONDITION 1 < CONDITION 2	0.74
300M STEEL	EHC R = -1	EHC/WFS R = -1	LCF	CONDITION 1 < CONDITION 2	0.82	CONDITION 1 < CONDITION 2	0.84
	EHC R = 0.1	EHC/WFS R = 0.1	LCF	CONDITION 1 < CONDITION 2	0.94	CONDITION 1 < CONDITION 2	0.93
13-8PH STAINLESS STEEL	EHC R = -1	EHC/WFS R = -1	HCF	CONDITION 1 < CONDITION 2	>0.99	NO COMPARISON POSSIBLE	
	EHC R = 0.1	EHC/WFS R = 0.1	HCF	CONDITION 1 < CONDITION 2	0.98	CONDITION 1 < CONDITION 2	0.97
13-8PH STAINLESS STEEL	EHC R = -1	EHC/WFS R = -1	LCF	NO COMPARISON POSSIBLE		NO COMPARISON POSSIBLE	
	EHC R = 0.1	EHC/WFS R = 0.1	LCF	CONDITION 1 < CONDITION 2	0.85	CONDITION 1 < CONDITION 2	0.89

Appendix A- Part 2

Axial Fatigue Data for Aermet 100 Steel

Appendix A(a) Aermet 100 Low-Cycle Fatigue

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Aug-01

Total Number of Specimens: 6

Material Description: Aermet 100

TEST MACHINE: IRWIN

Load Cell S/N: 1870
Extensometer S/N: 367

Settings:

Load Cell Range: 10 kips
Extensometer Range: 0.010

Alignment Method: MTS EZALIGN

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
100A-1	-1	RT	0.75	0.2500	0.04908	0.0066	10,001	Suspended test
100A-4	-1	RT	0.75	0.2500	0.04908	0.0066	10,001	Suspended test
100A-2	-1	RT	0.75	0.2500	0.04908	0.0066	8,728	Knife edges moved (invalid test)
100A-3	-1	RT	0.75	0.2500	0.04908	0.0066	10,001	Suspended test
100A-25	-1	RT	0.75	0.2500	0.04908	0.0066	20,002	Suspended test
100A-26	-1	RT	0.75	0.2490	0.04870	0.0066	10,000	Suspended test Tested on Interlaken with Ext. 1322547

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Robert E. Taylor (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 16-Dec-01

Total Number of Specimens: 4

Material Description: Aermet 100

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: MTS EZALIGN

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
100A-13	0.1	RT	0.75	0.2490	0.04870	0.0140	4,295	Broke in center
100A-14	0.1	RT	0.75	0.2490	0.04870	0.0140	6,085	Broke in center
100A-15	0.1	RT	0.75	0.2490	0.04870	0.0140	6,655	Broke in center
100A-16	0.1	RT	0.75	0.2490	0.04870	0.0140	6,235	Broke in center

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 14-Mar-02

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
100A-5	-1	RT	0.75	0.2550	0.05107	0.0066	2,151	Broke at top radius outside gage length
100A-6	-1	RT	0.75	0.2550	0.05107	0.0066	4,029	Broke at top radius outside gage length
100A-7	-1	RT	0.75	0.2545	0.05087	0.0066	4,627	Broke in gage length
100A-8	-1	RT	0.75	0.2545	0.05087	0.0066	1,471	Broke at top of gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 14-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 21-Mar-02

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
100A-17	0.1	RT	0.75	0.2555	0.05127	0.0140	3,357	Crack in center of gage length
100A-34	0.1	RT	0.75	0.2545	0.05087	0.0140	2,333	Broke in center of gage length
100A-19	0.1	RT	0.75	0.2560	0.05147	0.0140	1,864	Broke in center of gage length
100A-20	0.1	RT	0.75	0.2535	0.05047	0.0140	2,774	Crack in center of gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 27-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated with fume suppressant (EHC/WFS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
100A-9	-1	RT	0.75	0.2530	0.05027	0.0066	4,280	Specimen failed in center
100A-10	-1	RT	0.75	0.2540	0.05067	0.0066	2,764	Specimen failed in upper radius
100A-11	-1	RT	0.75	0.2540	0.05067	0.0066	2,746	Specimen failed in lower radius
100A-12	-1	RT	0.75	0.2530	0.05027	0.0066	3,495	Specimen failed in center

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated with fume suppressant (EHC/WFS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
100A-21	0.1	RT	0.75	0.2530	0.05027	0.0140	2,036	Specimen failed in center
100A-22	0.1	RT	0.75	0.2540	0.05067	0.0140	2,590	Specimen failed in center
100A-23	0.1	RT	0.75	0.2540	0.05067	0.0140	2,694	Specimen failed in center
100A-24	0.1	RT	0.75	0.2540	0.05067	0.0140	2,956	Specimen failed in lower center of gage section

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

Appendix A (b)- Aermet 100 High-Cycle Fatigue

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Dec-01

Total Number of Specimens: 8

Material Description: Aermet 100

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: MTS EZALIGN

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
100B-25	-1	RT	0.75	0.2505	0.04928	140	6902.5	5,500,000	Broke, wrong stress level applied (invalid test)
100B-1	-1	RT	0.75	0.2530	0.05027	110	5530.0	3,286,010	Broke in upper grip
100B-3	-1	RT	0.75	0.2510	0.04948	110	5442.9	10,000,000	Run-out
100B-2	-1	RT	0.75	0.2520	0.04988	110	5486.8	1,728,823	Broke in center
100B-4	-1	RT	0.75	0.2520	0.04988	110	5486.8	1,789,894	Broke in center
100B-26	-1	RT	0.75	0.2510	0.04948	110	5442.9	10,000,000	Run-out
100B-27	-1	RT	0.75	0.2520	0.04988	110	5486.8	269,927	Broke in center
100B-32	-1	RT	0.75	0.2510	0.04948	110	5442.8	10,000,000	Run-out

COMMENTS: High cycle fatigue – Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Dec-01

Total Number of Specimens: 5

Material Description: Aermet 100

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: MTS EZALIGN

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
100B-13	0.1	RT	0.75	0.2520	0.04985	160	7976.0	10,000,000	Run-out
100B-14	0.1	RT	0.75	0.2515	0.04968	160	7948.8	432,088	Broke in center
100B-15	0.1	RT	0.75	0.2520	0.04985	160	7976.0	10,000,000	Run-out
100B-16	0.1	RT	0.75	0.2520	0.04985	160	7976.0	10,000,000	Run-out
100B-31	0.1	RT	0.75	0.2515	0.04968	160	7948.8	10,000,000	Run-out

COMMENTS: High cycle fatigue – Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 14-Mar-02

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
100B-28	-1	RT	0.75	0.2565	0.05167	110	5683.7	14,437	Broke in gage length
100B-6	-1	RT	0.75	0.2580	0.05228	110	5750.8	13,603	Broke in gage length
100B-7	-1	RT	0.75	0.2600	0.05309	110	5840.0	11,776	Broke in gage length
100B-8	-1	RT	0.75	0.2590	0.05269	110	5795.9	12,446	Broke in gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 14-Mar-02

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
100B-17	0.1	RT	0.75	0.2580	0.05228	160	8364.8	8,617	Broke in gage length
100B-18	0.1	RT	0.75	0.2580	0.05228	160	8364.8	8,853	Broke in gage length
100B-34	0.1	RT	0.75	0.2575	0.05208	160	8332.8	8,280	Broke in gage length
100B-20	0.1	RT	0.75	0.2580	0.05228	160	8364.8	44,090	Broke in gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated with fume suppressant (EHC/FS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
100B-9	-1	RT	0.75	0.2560	0.05147	110	5661.7	17,518	Failed in center
100B-10	-1	RT	0.75	0.2550	0.05107	110	5617.7	17,168	Failed in center
100B-11	-1	RT	0.75	0.2555	0.05127	110	5639.7	17,977	Failed in bottom center inside gage length
100B-12	-1	RT	0.75	0.2545	0.05087	110	5595.7	17,207	Failed in center

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: Aermet 100 chrome plated with fume suppressant (EHC/FS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
100B-21	0.1	RT	0.75	0.2550	0.05107	160	8171.2	10,658	Failed in upper center outside gage length
100B-22	0.1	RT	0.75	0.2560	0.05147	160	8235.2	11,000	Failed in center
100B-23	0.1	RT	0.75	0.2560	0.05147	160	8235.2	10,811	Failed in upper center inside gage length
100B-24	0.1	RT	0.75	0.2555	0.05127	160	8203.2	10,914	Failed in bottom center outside gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

Appendix B - Axial Fatigue Data for 300M Steel

Appendix B (a) - 300M Low-Cycle Fatigue

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 19-Mar-02

Total Number of Specimens: 4

Material Description: 300M chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
300A-5	-1	RT	0.75	0.2545	0.05087	0.0057	4,264	Broke in gage length
300A-6	-1	RT	0.75	0.2545	0.05087	0.0057	2,078	Broke in gage length
300A-7	-1	RT	0.75	0.2540	0.05067	0.0057	3,896	Broke in gage length
300A-8	-1	RT	0.75	0.2545	0.05087	0.0057	1,983	Broke in gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 25-Mar-02

Total Number of Specimens: 5

Material Description: 300M chrome plated (EHC)

TEST MACHINE: INTERLAKEN	**Settings:**	**Specimen:**
Load Cell S/N: 50071 Extensometer S/N: 1322547	Load Cell Range: 25 kips Extensometer Range: 0.030 Alignment Method: Dial indicator Test Rate: 0.4 Hz	Geometry: 0.25 in. diameter Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
300A-17	0.1	RT	0.75	0.2555	0.05127	0.0110	3,115	Broke in center of gage length
300A-18	0.1	RT	0.75	0.2545	0.05087	0.0110	2,862	Broke in center of gage length
300A-19	0.1	RT	0.75	0.2555	0.05127	0.0110	2,605	Broke in center of gage length
300A-20	0.1	RT	0.75	0.2545	0.05087	0.0110	1,916	Broke in lower radius
300A-36	0.1	RT	0.75	0.2545	0.05087	0.0110	3,490	Broke in center of gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 27-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 19-Mar-02

Total Number of Specimens: 4

Material Description: 300M chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
300A-5	-1	RT	0.75	0.2545	0.05087	0.0057	4,264	Broke in gage length
300A-6	-1	RT	0.75	0.2545	0.05087	0.0057	2,078	Broke in gage length
300A-7	-1	RT	0.75	0.2540	0.05067	0.0057	3,896	Broke in gage length
300A-8	-1	RT	0.75	0.2545	0.05087	0.0057	1,983	Broke in gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 25-Mar-02

Total Number of Specimens: 5

Material Description: 300M chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
300A-17	0.1	RT	0.75	0.2555	0.05127	0.0110	3,115	Broke in center of gage length
300A-18	0.1	RT	0.75	0.2545	0.05087	0.0110	2,862	Broke in center of gage length
300A-19	0.1	RT	0.75	0.2555	0.05127	0.0110	2,605	Broke in center of gage length
300A-20	0.1	RT	0.75	0.2545	0.05087	0.0110	1,916	Broke in lower radius
300A-36	0.1	RT	0.75	0.2545	0.05087	0.0110	3,490	Broke in center of gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 27-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: 300M chrome plated with fume suppressant (EHC/WFS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
300A-9	-1	RT	0.75	0.2530	0.05027	0.0057	8,480	Specimen failed in center
300A-10	-1	RT	0.75	0.2520	0.04988	0.0057	4,040	Specimen failed in bottom center of gage section
300A-11	-1	RT	0.75	0.2520	0.04988	0.0057	4,100	Specimen failed in center
300A-12	-1	RT	0.75	0.2520	0.04988	0.0057	4,515	Specimen failed in center

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: 300M chrome plated with fume suppressant (EHC/WFS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
300A-21	0.1	RT	0.75	0.2525	0.05007	0.0110	3,956	Specimen failed in center
300A-22	0.1	RT	0.75	0.2525	0.05007	0.0110	3,405	Specimen failed in center
300A-23	0.1	RT	0.75	0.2525	0.05007	0.0110	3,703	Specimen failed in center
300A-24	0.1	RT	0.75	0.2515	0.04968	0.0110	4,440	Specimen failed above and below center in gage section

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

Appendix B (b) – 300M High Cycle Fatigue

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Dec-01

Total Number of Specimens: 5

Material Description: 300M

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: MTS EZALIGN

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
300B-2	-1	RT	0.75	0.2530	0.05027	95	4775.6	215,087	Broke in center
300B-1	-1	RT	0.75	0.2530	0.05027	95	4775.6	10,000,000	Run-out
300B-3	-1	RT	0.75	0.2520	0.04985	95	4735.8	10,000,000	Run-out
300B-4	-1	RT	0.75	0.2525	0.05005	95	4754.6	10,000,000	Run-out
300B-25	-1	RT	0.75	0.2530	0.05027	95	4775.6	10,000,000	Run-out

COMMENTS: High cycle fatigue – Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Dec-01

Total Number of Specimens: 4

Material Description: 300M

TEST MACHINE: INTERLAKEN

Settings:

Specimen:

Load Cell S/N: 50071
Extensometer S/N: N/A

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: MTS EZALIGN

Test Rate: 30 Hz

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
300B-13	0.1	RT	0.75	0.2520	0.04985	135	6729.8	10,000,000	Run-out
300B-14	0.1	RT	0.75	0.2525	0.05005	135	6756.5	10,000,000	Run-out
300B-15	0.1	RT	0.75	0.2520	0.04985	135	6729.8	10,000,000	Run-out
300B-16	0.1	RT	0.75	0.2520	0.04985	135	6729.8	10,000,000	Run-out

COMMENTS: High cycle fatigue – Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Mar-02

Total Number of Specimens: 4

Material Description: 300M chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
300B-5	-1	RT	0.75	0.2590	0.05269	95	5005.6	25,755	Broke in gage length
300B-6	-1	RT	0.75	0.2590	0.05269	95	5005.6	24,437	Broke in gage length
300B-7	-1	RT	0.75	0.2585	0.05248	95	4985.6	24,255	Broke in gage length
300B-8	-1	RT	0.75	0.2590	0.05269	95	5005.6	23,775	Broke in gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 14-Mar-02

Total Number of Specimens: 4

Material Description: 300M chrome plated (EHC)

TEST MACHINE: 20 KIP MTS (RM 206C)

Load Cell S/N: 815
Extensometer S/N: N/A

Settings:

Load Cell Range: 10 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
300B-17	0.1	RT	0.75	0.2600	0.05309	135	7168.0	20,192	Broke in gage length
300B-18	0.1	RT	0.75	0.2585	0.05248	135	7085.0	13,705	Broke in gage length
300B-19	0.1	RT	0.75	0.2590	0.05269	135	7113.0	20,482	Broke in gage length
300B-20	0.1	RT	0.75	0.2610	0.05350	135	7223.0	19,262	Broke in gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Robert E. Taylor (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 5

Material Description: 300M chrome plated with fume suppressant (EHC/FS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
300B-9	-1	RT	0.75	0.2545	0.05087	95	4832.7	25,154	Failed in center
300B-10	-1	RT	0.75	0.2550	0.05107	95	4851.7	26,204	Failed in upper center inside gage length
300B-11	-1	RT	0.75	0.2555	0.05127	95	4870.7	25,392	Failed in upper center inside gage length
300B-12	-1	RT	0.75	0.2560	0.05147	95	4889.7	25,723	Failed in upper center outside gage length
300B-21	-1	RT	0.75	0.2555	0.05127	95	4870.7	26,978	Failed in center

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 3

Material Description: 300M chrome plated with fume suppressant (EHC/FS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
300B-22	0.1	RT	0.75	0.2550	0.05107	135	6894.5	18,829	Failed in center
300B-23	0.1	RT	0.75	0.2550	0.05107	135	6894.5	19,975	Failed in lower center inside gage length
300B-24	0.1	RT	0.75	0.2550	0.05107	135	6894.5	21,976	Failed in center

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

Appendix C - Axial Fatigue Data for 13-8PH Steel

Appendix C (a)- 13-8PH Low-Cycle Fatigue

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 16-Dec-01

Total Number of Specimens: 4

Material Description: 13-8PH

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: MTS EZALIGN

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
13-8A-1	-1	RT	0.75	0.2490	0.04870	0.0054	10,000	Suspended test
13-8A-2	-1	RT	0.75	0.2490	0.04870	0.0054	10,000	Suspended test
13-8A-3	-1	RT	0.75	0.2490	0.04870	0.0054	10,000	Suspended test
13-8A-4	-1	RT	0.75	0.2490	0.04870	0.0054	10,000	Suspended test

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 16-Dec-01

Total Number of Specimens: 4

Material Description: 13-8PH

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: MTS EZALIGN

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
13-8A-13	0.1	RT	0.75	0.2490	0.04870	0.0080	10,000	Suspended test
13-8A-14	0.1	RT	0.75	0.2490	0.04870	0.0080	10,000	Suspended test
13-8A-15	0.1	RT	0.75	0.2490	0.04870	0.0080	10,000	Suspended test
13-8A-16	0.1	RT	0.75	0.2490	0.04870	0.0080	10,000	Suspended test

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 21-Mar-02

Total Number of Specimens: 5

Material Description: 13-8PH chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
13-8A-30	-1	RT	0.75	0.2540	0.05067	0.0054	6,640	Broke at top of gage length
13-8A-5	-1	RT	0.75	0.2545	0.05087	0.0054	7,284	Broke at bottom of gage length
13-8A-6	-1	RT	0.75	0.2560	0.05147	0.0054	9,233	Broke at center of gage length
13-8A-7	-1	RT	0.75	0.2535	0.05047	0.0054	7,630	Broke at bottom radius outside gage length
13-8A-8	-1	RT	0.75	0.2555	0.05127	0.0054	10,000	Suspended test

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 21-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 22-Mar-02

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated (EHC)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
13-8A-17	0.1	RT	0.75	0.2550	0.05107	0.0080	8,250	Crack in center of gage section
13-8A-18	0.1	RT	0.75	0.2545	0.05087	0.0080	2,250	Crack in center of gage section
13-8A-19	0.1	RT	0.75	0.2550	0.05107	0.0080	8,200	Crack in center of gage section
13-8A-20	0.1	RT	0.75	0.2555	0.05127	0.0080	8,144	Crack in center of gage section

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 27-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated with fume suppressant (EHC/WFS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
13-8A-9	-1	RT	0.75	0.2520	0.04988	0.0054	9,716	Specimen failed on top, outside gage length - cracks in center
13-8A-10	-1	RT	0.75	0.2520	0.04988	0.0054	6,585	Specimen failed on bottom, outside gage length
13-8A-11	-1	RT	0.75	0.2520	0.04988	0.0054	9,401	Specimen failed on top, outside gage length - cracks in center
13-8A-12	-1	RT	0.75	0.2505	0.04928	0.0054	8,170	Specimen failed on top, outside gage length - cracks in gage

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated with fume suppressant (EHC/WFS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: 1322547

Settings:

Load Cell Range: 25 kips
Extensometer Range: 0.030

Alignment Method: Dial indicator

Test Rate: 0.4 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Strain Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Strain (in./in.)	Cycles	Remarks
13-8A-21	0.1	RT	0.75	0.2505	0.04928	0.0080	8,800	Specimen failed in center
13-8A-22	0.1	RT	0.75	0.2510	0.04948	0.0080	10,000	Suspended test
13-8A-23	0.1	RT	0.75	0.2520	0.04988	0.0080	9,616	Specimen failed on top, outside gage length
13-8A-24	0.1	RT	0.75	0.2525	0.05007	0.0080	9,741	Specimen failed top of center, inside gage length

COMMENTS: Low cycle fatigue – Tests without failures suspended at 10,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

Appendix C (b)- 13-8PH High-Cycle Fatigue

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Dec-01

Total Number of Specimens: 4

Material Description: 13-8PH

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: MTS EZALIGN

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
13-8B-1	-1	RT	0.75	0.2525	0.05005	85	4254.1	10,000,000	Run-out
13-8B-2	-1	RT	0.75	0.2520	0.04985	85	4237.3	10,000,000	Run-out
13-8B-3	-1	RT	0.75	0.2535	0.05047	85	4290.0	10,000,000	Run-out
13-8B-4	-1	RT	0.75	0.2530	0.05027	85	4273.0	10,000,000	Run-out

COMMENTS: High cycle fatigue – Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 02-Dec-01

Total Number of Specimens: 4

Material Description: 13-8PH

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: MTS EZALIGN

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
13-8B-13	0.1	RT	0.75	0.2525	0.05005	150	7507.5	10,000,000	Run-out
13-8B-14	0.1	RT	0.75	0.2525	0.05005	150	7507.5	10,000,000	Run-out
13-8B-15	0.1	RT	0.75	0.2525	0.05005	150	7507.5	10,000,000	Run-out
13-8B-16	0.1	RT	0.75	0.2525	0.05005	150	7507.5	10,000,000	Run-out

COMMENTS: High cycle fatigue – Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 03-Jan-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 13-Mar-02

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated (EHC)

TEST MACHINE: 20 KIP MTS (RM 206C)

Load Cell S/N: 815
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
13-8B-5	-1	RT	0.75	0.2590	0.05269	85	4478.7	37,705	Broke in gage length
13-8B-6	-1	RT	0.75	0.2565	0.05168	85	4392.3	36,142	Broke in gage length
13-8B-7	-1	RT	0.75	0.2580	0.05228	85	4443.9	36,958	Broke in gage length
13-8B-8	-1	RT	0.75	0.2595	0.05289	85	4495.7	41,340	Broke in gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Robert E. Taylor (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 14-Mar-02

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated (EHC)

TEST MACHINE: 20 KIP MTS (RM 206C)

Load Cell S/N: 815
Extensometer S/N: N/A

Settings:

Load Cell Range: 10 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter(in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
13-8B-17	0.1	RT	0.75	0.2585	0.05248	150	7872.5	14,912	Broke in gage length
13-8B-18	0.1	RT	0.75	0.2575	0.05208	150	7812.0	18,228	Broke in gage length
13-8B-19	0.1	RT	0.75	0.2575	0.05208	150	7812.0	17,786	Broke in gage length
13-8B-20	0.1	RT	0.75	0.2575	0.05208	150	7812.0	15,650	Broke in gage length

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Robert E. Taylor (signature on file)

Date: 19-Mar-02

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated with fume suppressant (EHC/FS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
13-8B-9	-1	RT	0.75	0.2560	0.05147	85	4375.0	55,892	Failed in upper center inside gage length
13-8B-10	-1	RT	0.75	0.2545	0.05087	85	4324.0	60,771	Failed in center
13-8B-11	-1	RT	0.75	0.2545	0.05087	85	4324.0	61,173	Failed in center
13-8B-12	-1	RT	0.75	0.2535	0.05047	85	4290.0	62,901	Failed in center

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

FATIGUE DATA REPORT
Mechanical Test Laboratory, RM 106A

Laboratory Report: MT1089

Test Completion Date: 12-Feb-03

Total Number of Specimens: 4

Material Description: 13-8PH chrome plated with fume suppressant (EHC/FS)

TEST MACHINE: INTERLAKEN

Load Cell S/N: 50071
Extensometer S/N: N/A

Settings:

Load Cell Range: 25 kips
Extensometer Range: N/A

Alignment Method: Dial indicator

Test Rate: 30 Hz

Specimen:

Geometry: 0.25 in. diameter
Nominal Gage: 0.75 in.

TEST RESULTS

Specimen ID	Stress Ratio	Temp (F)	Initial Gage (in.)	Diameter (in.)	Initial Area (in^2)	Stress (ksi)	Load (lbs)	Cycles	Remarks
13-8B-21	0.1	RT	0.75	0.2550	0.05107	150	7660.5	20,697	Failed in lower center inside gage length
13-8B-22	0.1	RT	0.75	0.2550	0.05107	150	7660.5	20,944	Failed in upper center inside gage length
13-8B-23	0.1	RT	0.75	0.2535	0.05047	150	7570.5	25,142	Failed in center
13-8B-24	0.1	RT	0.75	0.2555	0.05127	150	7690.5	21,502	Failed in center

COMMENTS: High cycle fatigue - Run-out defined as 10,000,000 cycles

Analyst: Henry C. Sanders (signature on file)

Date: 13-Feb-03

Appendix D - Axial Fatigue Test Matrix

Matrix 1_6

ESTCP WAFS Fatigue Testing
Plating Thickness: 3 mils on all samples

Strain Controlled Low-Cycle Fatigue
10,000 cycles @ 0.4 Hz

Coupon #	Alloy	Coating	R value	Approximate Strain	Cycles to Failure
100A-1	Aermet 100	none	-1	0.00660	
100A-2	Aermet 100	none	-1	0.00660	
100A-3	Aermet 100	none	-1	0.00660	
100A-4	Aermet 100	none	-1	0.00660	
300A-1	300M	none	-1	0.00570	
300A-2	300M	none	-1	0.00570	
300A-3	300M	none	-1	0.00570	
300A-4	300M	none	-1	0.00570	
13-8A-1	13-8	none	-1	0.00540	
13-8A-2	13-8	none	-1	0.00540	
13-8A-3	13-8	none	-1	0.00540	
13-8A-4	13-8	none	-1	0.00540	
100A-5	Aermet 100	EHC	-1	0.00660	
100A-6	Aermet 100	EHC	-1	0.00660	
100A-7	Aermet 100	EHC	-1	0.00660	
100A-8	Aermet 100	EHC	-1	0.00660	
300A-5	300M	EHC	-1	0.00570	
300A-6	300M	EHC	-1	0.00570	
300A-7	300M	EHC	-1	0.00570	
300A-8	300M	EHC	-1	0.00570	
13-8A-5	13-8	EHC	-1	0.00540	
13-8A-6	13-8	EHC	-1	0.00540	
13-8A-7	13-8	EHC	-1	0.00540	
13-8A-8	13-8	EHC	-1	0.00540	
100A-9	Aermet 100	EHC w/WAFS	-1	0.00660	
100A-10	Aermet 100	EHC w/WAFS	-1	0.00660	
100A-11	Aermet 100	EHC w/WAFS	-1	0.00660	
100A-12	Aermet 100	EHC w/WAFS	-1	0.00660	
300A-9	300M	EHC w/WAFS	-1	0.00570	
300A-10	300M	EHC w/WAFS	-1	0.00570	
300A-11	300M	EHC w/WAFS	-1	0.00570	
300A-12	300M	EHC w/WAFS	-1	0.00570	
13-8A-9	13-8	EHC w/WAFS	-1	0.00540	
13-8A-10	13-8	EHC w/WAFS	-1	0.00540	
13-8A-11	13-8	EHC w/WAFS	-1	0.00540	
13-8A-12	13-8	EHC w/WAFS	-1	0.00540	
100A-13	Aermet 100	none	0.1	0.01400	
100A-14	Aermet 100	none	0.1	0.01400	
100A-15	Aermet 100	none	0.1	0.01400	
100A-16	Aermet 100	none	0.1	0.01400	
300A-13	300M	none	0.1	0.01100	
300A-14	300M	none	0.1	0.01100	
300A-15	300M	none	0.1	0.01100	
300A-16	300M	none	0.1	0.01100	
13-8A-13	13-8	none	0.1	0.00800	
13-8A-14	13-8	none	0.1	0.00800	
13-8A-15	13-8	none	0.1	0.00800	
13-8A-16	13-8	none	0.1	0.00800	
100A-17	Aermet 100	EHC	0.1	0.01400	
100A-18	Aermet 100	EHC	0.1	0.01400	
100A-19	Aermet 100	EHC	0.1	0.01400	
100A-20	Aermet 100	EHC	0.1	0.01400	
300A-17	300M	EHC	0.1	0.01100	
300A-18	300M	EHC	0.1	0.01100	
300A-19	300M	EHC	0.1	0.01100	
300A-20	300M	EHC	0.1	0.01100	
13-8A-17	13-8	EHC	0.1	0.00800	
13-8A-18	13-8	EHC	0.1	0.00800	
13-8A-19	13-8	EHC	0.1	0.00800	
13-8A-20	13-8	EHC	0.1	0.00800	
100A-21	Aermet 100	EHC w/WAFS	0.1	0.01400	
100A-22	Aermet 100	EHC w/WAFS	0.1	0.01400	
100A-23	Aermet 100	EHC w/WAFS	0.1	0.01400	
100A-24	Aermet 100	EHC w/WAFS	0.1	0.01400	
300A-21	300M	EHC w/WAFS	0.1	0.01100	
300A-22	300M	EHC w/WAFS	0.1	0.01100	
300A-23	300M	EHC w/WAFS	0.1	0.01100	
300A-24	300M	EHC w/WAFS	0.1	0.01100	
13-8A-21	13-8	EHC w/WAFS	0.1	0.00800	
13-8A-22	13-8	EHC w/WAFS	0.1	0.00800	

Stress Controlled High-Cycle Fatigue
10,000,000 cycles @ 30 Hz

Coupon #	Alloy	Coating	R value	Approximate Stress (ksi)	Cycles to Failure
100B-1	Aermet 100	none	-1	110	
100B-2	Aermet 100	none	-1	110	
100B-3	Aermet 100	none	-1	110	
100B-4	Aermet 100	none	-1	110	
300B-1	300M	none	-1	95	
300B-2	300M	none	-1	95	
300B-3	300M	none	-1	95	
300B-4	300M	none	-1	95	
13-8B-1	13-8	none	-1	85	
13-8B-2	13-8	none	-1	85	
13-8B-3	13-8	none	-1	85	
13-8B-4	13-8	none	-1	85	
100B-5	Aermet 100	EHC	-1	110	
100B-6	Aermet 100	EHC	-1	110	
100B-7	Aermet 100	EHC	-1	110	
100B-8	Aermet 100	EHC	-1	110	
300B-5	300M	EHC	-1	95	
300B-6	300M	EHC	-1	95	
300B-7	300M	EHC	-1	95	
300B-8	300M	EHC	-1	95	
13-8B-5	13-8	EHC	-1	85	
13-8B-6	13-8	EHC	-1	85	
13-8B-7	13-8	EHC	-1	85	
13-8B-8	13-8	EHC	-1	85	
100B-9	Aermet 100	EHC w/WAFS	-1	110	
100B-10	Aermet 100	EHC w/WAFS	-1	110	
100B-11	Aermet 100	EHC w/WAFS	-1	110	
100B-12	Aermet 100	EHC w/WAFS	-1	110	
300B-9	300M	EHC w/WAFS	-1	95	
300B-10	300M	EHC w/WAFS	-1	95	
300B-11	300M	EHC w/WAFS	-1	95	
300B-12	300M	EHC w/WAFS	-1	95	
13-8B-9	13-8	EHC w/WAFS	-1	85	
13-8B-10	13-8	EHC w/WAFS	-1	85	
13-8B-11	13-8	EHC w/WAFS	-1	85	
13-8B-12	13-8	EHC w/WAFS	-1	85	
100B-13	Aermet 100	none	0.1	160	
100B-14	Aermet 100	none	0.1	160	
100B-15	Aermet 100	none	0.1	160	
100B-16	Aermet 100	none	0.1	160	
300B-13	300M	none	0.1	135	
300B-14	300M	none	0.1	135	
300B-15	300M	none	0.1	135	
300B-16	300M	none	0.1	135	
13-8B-13	13-8	none	0.1	150	
13-8B-14	13-8	none	0.1	150	
13-8B-15	13-8	none	0.1	150	
13-8B-16	13-8	none	0.1	150	
100B-17	Aermet 100	EHC	0.1	160	
100B-18	Aermet 100	EHC	0.1	160	
100B-19	Aermet 100	EHC	0.1	160	
100B-20	Aermet 100	EHC	0.1	160	
300B-17	300M	EHC	0.1	135	
300B-18	300M	EHC	0.1	135	
300B-19	300M	EHC	0.1	135	
300B-20	300M	EHC	0.1	135	
13-8B-17	13-8	EHC	0.1	150	
13-8B-18	13-8	EHC	0.1	150	
13-8B-19	13-8	EHC	0.1	150	
13-8B-20	13-8	EHC	0.1	150	
100B-21	Aermet 100	EHC w/WAFS	0.1	160	
100B-22	Aermet 100	EHC w/WAFS	0.1	160	
100B-23	Aermet 100	EHC w/WAFS	0.1	160	
100B-24	Aermet 100	EHC w/WAFS	0.1	160	
300B-21	300M	EHC w/WAFS	0.1	135	
300B-22	300M	EHC w/WAFS	0.1	135	
300B-23	300M	EHC w/WAFS	0.1	135	
300B-24	300M	EHC w/WAFS	0.1	135	
13-8B-21	13-8	EHC w/WAFS	0.1	150	
13-8B-22	13-8	EHC w/WAFS	0.1	150	

Matrix 1_6

ESTCP WAFS Fatigue Testing
Plating Thickness: 3 mils on all samples

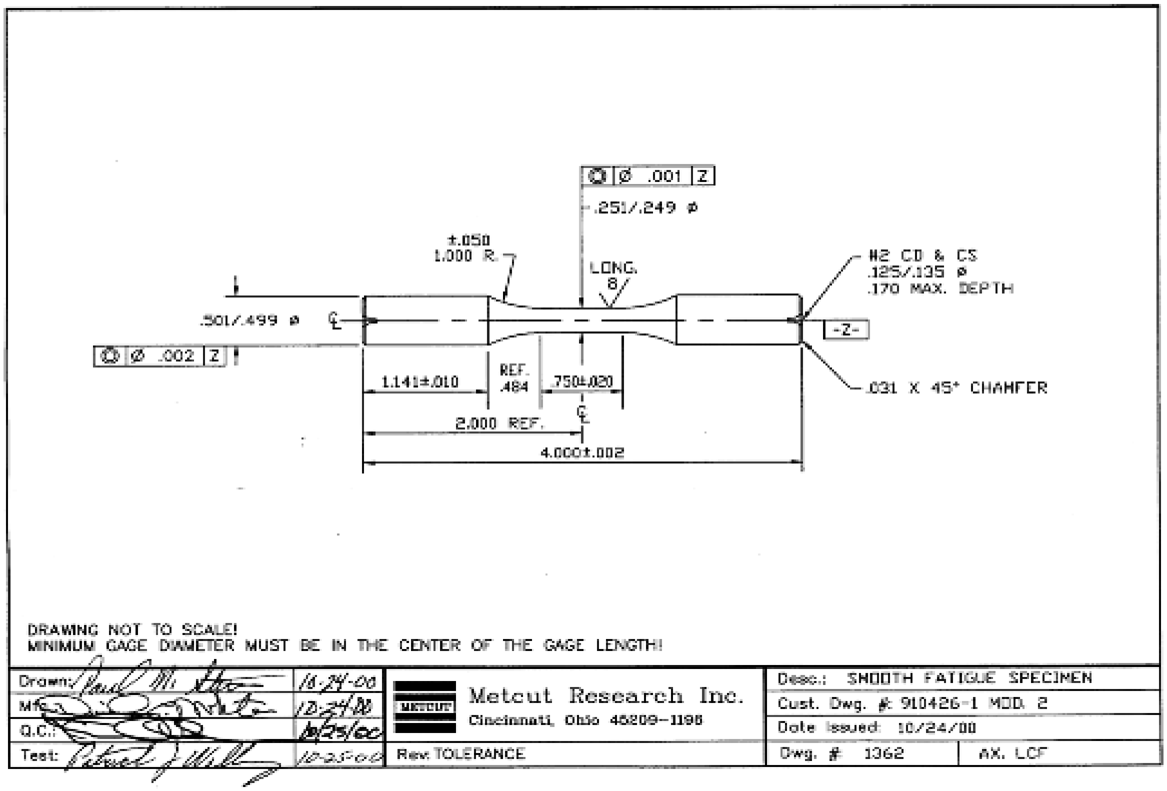
Strain Controlled Low-Cycle Fatigue
10,000 cycles @ 0.4 Hz

Coupon #	Alloy	Coating	R value	Approximate Strain	Cycles to Failure
13-8A-24	13-8	EHC w/WAFS	0.1	0.00800	
100A-25	Aermet 100	none	-1	0.00660	dummy
100A-26	Aermet 100	none	-1	0.00660	dummy
100A-27	Aermet 100	none	-1	0.00660	dummy
300A-25	300M	none	-1	0.00570	dummy
300A-26	300M	none	-1	0.00570	dummy
300A-27	300M	none	-1	0.00570	dummy
13-8A-25	13-8	none	-1	0.00540	dummy
13-8A-26	13-8	none	-1	0.00540	dummy
13-8A-27	13-8	none	-1	0.00540	dummy
100A-28	Aermet 100	EHC	-1	0.00660	dummy
100A-29	Aermet 100	EHC	-1	0.00660	dummy
100A-30	Aermet 100	EHC	-1	0.00660	dummy
300A-28	300M	EHC	-1	0.00570	dummy
300A-29	300M	EHC	-1	0.00570	dummy
300A-30	300M	EHC	-1	0.00570	dummy
13-8A-28	13-8	EHC	-1	0.00540	dummy
13-8A-29	13-8	EHC	-1	0.00540	dummy
13-8A-30	13-8	EHC	-1	0.00540	dummy
100A-31	Aermet 100	none	0.1	0.01400	dummy
100A-32	Aermet 100	none	0.1	0.01400	dummy
100A-33	Aermet 100	none	0.1	0.01400	dummy
300A-31	300M	none	0.1	0.01100	dummy
300A-32	300M	none	0.1	0.01100	dummy
300A-33	300M	none	0.1	0.01100	dummy
13-8A-31	13-8	none	0.1	0.00800	dummy
13-8A-32	13-8	none	0.1	0.00800	dummy
13-8A-33	13-8	none	0.1	0.00800	dummy
100A-34	Aermet 100	EHC	0.1	0.01400	dummy
100A-35	Aermet 100	EHC	0.1	0.01400	dummy
100A-36	Aermet 100	EHC	0.1	0.01400	dummy
300A-34	300M	EHC	0.1	0.01100	dummy
300A-35	300M	EHC	0.1	0.01100	dummy
300A-36	300M	EHC	0.1	0.01100	dummy
13-8A-34	13-8	EHC	0.1	0.00800	dummy
13-8A-35	13-8	EHC	0.1	0.00800	dummy
13-8A-36	13-8	EHC	0.1	0.00800	dummy

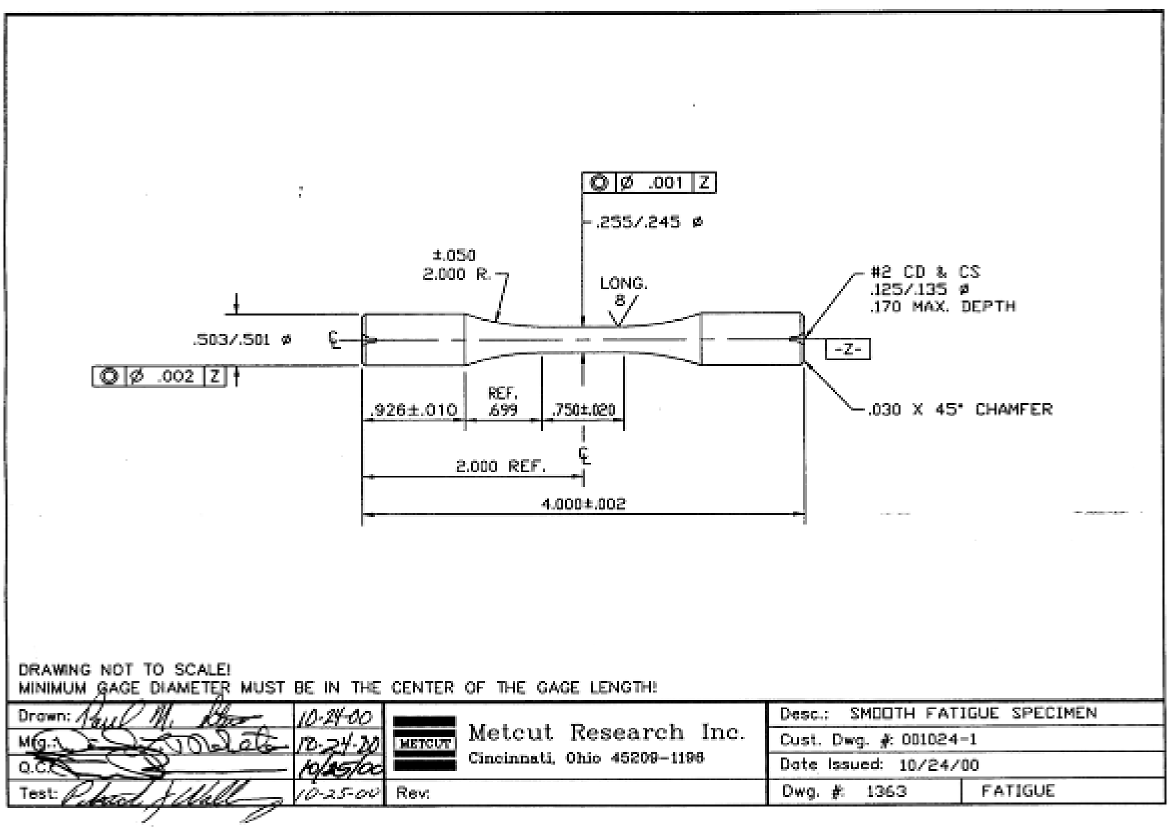
Stress Controlled High-Cycle Fatigue
10,000,000 cycles @ 30 Hz

Coupon #	Alloy	Coating	R value	Approximate Stress (ksi)	Cycles to Failure
13-8B-24	13-8	EHC w/WAFS	0.1	150	
100B-25	Aermet 100	none	-1	110	dummy
100B-26	Aermet 100	none	-1	110	dummy
100B-27	Aermet 100	none	-1	110	dummy
300B-25	300M	none	-1	95	dummy
300B-26	300M	none	-1	95	dummy
300B-27	300M	none	-1	95	dummy
13-8B-25	13-8	none	-1	85	dummy
13-8B-26	13-8	none	-1	85	dummy
13-8B-27	13-8	none	-1	85	dummy
100B-28	Aermet 100	EHC	-1	110	dummy
100B-29	Aermet 100	EHC	-1	110	dummy
100B-30	Aermet 100	EHC	-1	110	dummy
300B-28	300M	EHC	-1	95	dummy
300B-29	300M	EHC	-1	95	dummy
300B-30	300M	EHC	-1	95	dummy
13-8B-28	13-8	EHC	-1	85	dummy
13-8B-29	13-8	EHC	-1	85	dummy
13-8B-30	13-8	EHC	-1	85	dummy
100B-31	Aermet 100	none	0.1	160	dummy
100B-32	Aermet 100	none	0.1	160	dummy
100B-33	Aermet 100	none	0.1	160	dummy
300B-31	300M	none	0.1	135	dummy
300B-32	300M	none	0.1	135	dummy
300B-33	300M	none	0.1	135	dummy
13-8B-31	13-8	none	0.1	150	dummy
13-8B-32	13-8	none	0.1	150	dummy
13-8B-33	13-8	none	0.1	150	dummy
100B-34	Aermet 100	EHC	0.1	160	dummy
100B-35	Aermet 100	EHC	0.1	160	dummy
100B-36	Aermet 100	EHC	0.1	160	dummy
300B-34	300M	EHC	0.1	135	dummy
300B-35	300M	EHC	0.1	135	dummy
300B-36	300M	EHC	0.1	135	dummy
13-8B-34	13-8	EHC	0.1	150	dummy
13-8B-35	13-8	EHC	0.1	150	dummy
13-8B-36	13-8	EHC	0.1	150	dummy

	Unplated	EHC	EHC w/WAFS	Total Alloy
Total Aermet A/B	14	14	8	36
Total 300M A/B	14	14	8	36
Total 13-8 A/B	14	14	8	36
Total A/B	42	42	24	108



.001 Z
.251/.249 ø
±.050
1.000 R.
LONG.
8
#2 CD & CS
.125/.135 ø
.170 MAX. DEPTH
.501/.499 ø
-Z-
.002 Z
1.141±.010
REF.
.484
.750±.020
.031 X 45° CHAMFER
2.000 REF.
4.000±.002
DRAWING NOT TO SCALE!
MINIMUM GAGE DIAMETER MUST BE IN THE CENTER OF THE GAGE LENGTH!
Drawn:
10-24-00
Mfg.:
10-24-00
Q.C.:
10/25/00
Test:
10-25-00
Metcut Research Inc.
Cincinnati, Ohio 45209-1196
Rev: TOLERANCE
Desc.: SMOOTH FATIGUE SPECIMEN
Cust. Dwg. #: 910426-1 MOD. 2
Date Issued: 10/24/00
Dwg. #: 1362
AX. LCF



.001 Z
.255/.245 ø
±.050
2.000 R.
LONG.
8
#2 CD & CS
.125/.135 ø
.170 MAX. DEPTH
.503/.501 ø
-Z-
.002 Z
.926±.010
REF.
.699
.750±.020
.030 X 45° CHAMFER
2.000 REF.
4.000±.002
DRAWING NOT TO SCALE!
MINIMUM GAGE DIAMETER MUST BE IN THE CENTER OF THE GAGE LENGTH!
Drawn:
10-24-00
Mfg.:
10-24-00
Q.C.:
10/25/00
Test:
10-25-00
Metcut Research Inc.
Cincinnati, Ohio 45209-1196
Rev:
Desc.: SMOOTH FATIGUE SPECIMEN
Cust. Dwg. #: 001024-1
Date Issued: 10/24/00
Dwg. #: 1363
FATIGUE

APPENDIX G

HYDROGEN EMBRITTLEMENT DOCUMENTATION

Appendix G1: Results of 200-Hour Sustained Tensile Load Tests

DIRATS
LABORATORIES

TEST REPORT

Erin Beck
Naval Air Warfare Center
Aircraft Division
Mail Stop 5
Building 2188
Patuxent River, MD 20670

Report Number	341824
Report Date	16-MAR-01
Page	1 of 2
Client Number	580375
Client Order	01V0691390024

RECEIVED	18 ASTM F519-97 Type 1a Notched Round Bars from Dirats Lot AG
IDENT AS	Follows
MATERIAL	AISI 4340, Plated
CONDITION	*
TEST TO	Client Requirements
PURPOSE	Hydrogen Embrittlement Relief Test
FAX	301-342-7566

PROPERTIES AS SUPPLIED

SUSTAINED LOAD TEST ON PLATED V-NOTCHED SPECIMENS PER ASTM F519-97	Disp
LOT A	
S/N 1 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 3 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 4 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 5 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 6 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 7 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 8 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 9 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec

41 AIRPORT ROAD P.O. BOX 39 WESTFIELD, MA 01086-0039 FAX 413-568-1453 413-568-1571

DIRATS
LABORATORIES

TEST REPORT

Naval Air Warfare Center
Aircraft Division
Patuxent River, MD 20670

Report Number	341824
Report Date	16-MAR-01
Page	2 of 2

LOT B

S/N 1 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 3 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 4 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 5 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 6 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 7 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 8 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 9 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec

Required: A plkating process shall be considered acceptable quality if all four specimens life is 200 hours or greater.

NADCAP

WE CERTIFY THIS IS A TRUE COPY OF OUR RECORDS
Signed for J. Dirats and Co. by Eric E. Dirats, Audit Manager
NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal law.

41 AIRPORT ROAD P.O. BOX 39 WESTFIELD, MA 01086-0039 FAX 413-568-1453 413-568-1571

DIRATS
LABORATORIES

TEST REPORT

Erin Beck
Naval Air Warfare Center
Aircraft Division
Mail Stop 5
Building 2188
Patuxent River, MD 20670

Report Number	336726
Report Date	26-DEC-00
Page	1 of 2
Client Number	580375
Client Order	01V020650001

01V020656000 1
the proper PO #

Cred
Car

Dirats fax copy of invoice to cardholder. Cardholder give card # to Dirats over phone to p the bill.
Resubmit the KAPS if that perso not a cardholder anymore

RECEIVED	10 ASTM F519-97 Type 1a Notched Round Bars from Dirats Lot Al
IDENT AS	Lot 3
MATERIAL	AISI 4340, Plated
TEST TO	Client Requirements
PURPOSE	Hydrogen Embrittlement Relief Test
FAX	301-342-7566

PROPERTIES AS SUPPLIED

SUSTAINED LOAD TEST ON PLATED V-NOTCHED SPECIMENS PER ASTM F519-97	Disp
S/N 1 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 2 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 3 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 4 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 5 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 6 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 7 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec
S/N 8 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. Result: No rupture	In Spec

41 AIRPORT ROAD P.O. BOX 39 WESTFIELD, MA 01086-0039 FAX 413-568-1453 413-568-1571

DIRATS
LABORATORIES

TEST REPORT

Naval Air Warfare Center
Aircraft Division
Patuxent River, MD 20670

Report Number	**336726**
Report Date	**26-DEC-00**
Page	**2 of 2**

S/N 9 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. In Spec
Result: No rupture

S/N 10 was stressed for 200 hours at 75% of the notched UTS 293.5 ksi. In Spec
Result: No rupture

Required: A plating process shall be considered acceptable quality if all four specimens life is 200 hours or greater.

NADCAP

WE CERTIFY THIS IS A TRUE COPY OF OUR RECORDS
Signed for J. Dirats and Co. by Eric E. Dirats, Audit Manager
NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal law.

41 AIRPORT ROAD P.O. BOX 39 WESTFIELD, MA 01086-0039 FAX 413-568-1453 413-568-1571

DIRATS
LABORATORIES

TEST REPORT

Craig Matzdorf
Naval Air Warfare Center
Aircraft Division
Mail Stop 5
Building 2188
Patuxent River, MD 20670

Report Number	**335047**
Report Date	**29-NOV-00**
Page	**1 of 2**
Client Number	**580375**
Client Order	**01V02650001**

RECEIVED	20 ASTM F519-97 Type 1a Notched Round Bars from Dirats Lot AG
IDENT AS	Follows
MATERIAL	*
CONDITION	*
TEST TO	Client Requirements
FAX	301-342-7566

PROPERTIES AS SUPPLIED

SUSTAINED LOAD TEST ON PLATED V-NOTCHED SPECIMENS PER ASTM F519-97	Disp
S/N 1-1 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-2 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-3 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-4 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-5 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-6 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-7 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-8 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec

DIRATS
LABORATORIES

TEST REPORT

Naval Air Warfare Center
Aircraft Division
Patuxent River, MD 20670

Report Number	335047
Report Date	29-NOV-00
Page	2 of 2

S/N 1-9 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 1-10 Sample was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-1 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-2 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-3 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-4 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-5 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-6 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-7 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-8 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-9 was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec
S/N 2-10 Sample was stressed for 200 hours at 75% of the notched UTS 293.2 ksi. Result: No rupture	In Spec

Required: A plating process shall be considered acceptable quality if all four specimens life is 200 hours or greater.

NADCAP

WE CERTIFY THIS IS A TRUE COPY OF OUR RECORDS
Signed for J. Dirats and Co. by Eric E. Dirats, Audit Manager
NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal law.

41 AIRPORT ROAD P.O. BOX 39 WESTFIELD, MA 01086-0039 FAX 413-568-1453 413-568-1571

Appendix G2: Sample Results of 24-Hour Rising Step Load Tests

Summary Table: Results of 24-Hour Rising Step Load Testing

Comparison of fracture % of chrome plated 4340 steel with and without Fumitrol

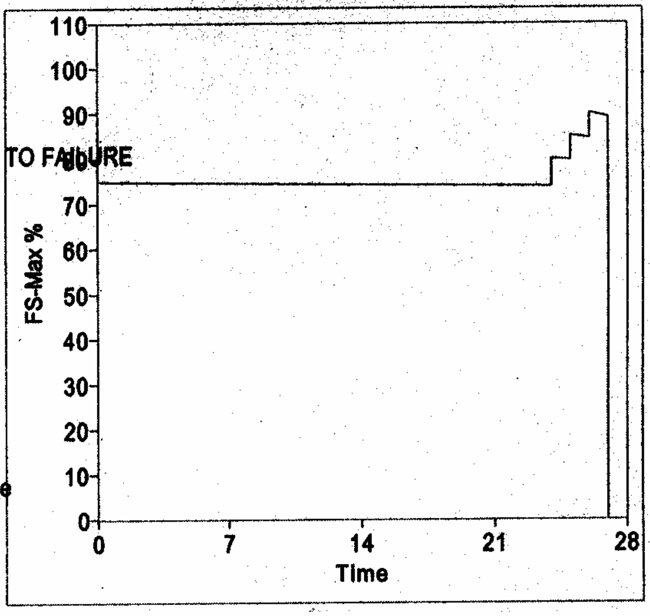
	Fracture %				
	Cherry Point w/o Fumitrol	Cherry Point w/ Fumitrol	North Island w/ Fumitrol	Tinker w/o Fumitrol	Tinker w/ Fumitrol
	92.6	92.8	91.0	93.7	93.8
	87.8	91.4	93.6	94.3	93.3
	91.2	89.0	91.4	91.5	93.8
	90.0	90.2	94.2	93	94.7
	92.3	92.7	91.1	92.3	93.3
	90.2	89.5	92.7	93.7	90.2
	93.1	90.2	93.2	93	93.3
	92.2	94.1	93.2	93.5	92.8
	74.0	93.2	93.1	90.6	93.8
	90.0		90.1		
	90.7				
Average	**89.5**	**91.5**	**92.4**	**92.8**	**93.2**

Example 24-Hour Rising Step Load Data for Each Set of Test Parameters
(Location, w/o WAFS, w/WAFS, no chrome control)

CP no WAFS Control

c:\rslsi\Craig Matzdorf\cp no wafs 24 hr bake 01.tst

Start Time: 09/14/00 11:01
Lot ID: AG
Sample #: 1465
Sample Type: Notched Round Bar
Method: 75% @ 24HR, STEP 5%/HR TO FAILURE
Test Type: Tension
Tensile Strength: 390.9 ksi
Fracture Strength: 9403.0
Fracture Load: 8706.1
Fracture %: 92.6
End Time: 09/15/00 14:01
System: Ten.01
Calibration Date: 09/14/00 10:59
Process ID: CP wo Fumitrol w 24 hr bake
Batch: Dirats/CP
Potential: No Potential Applied
Solution: Air
Comments:



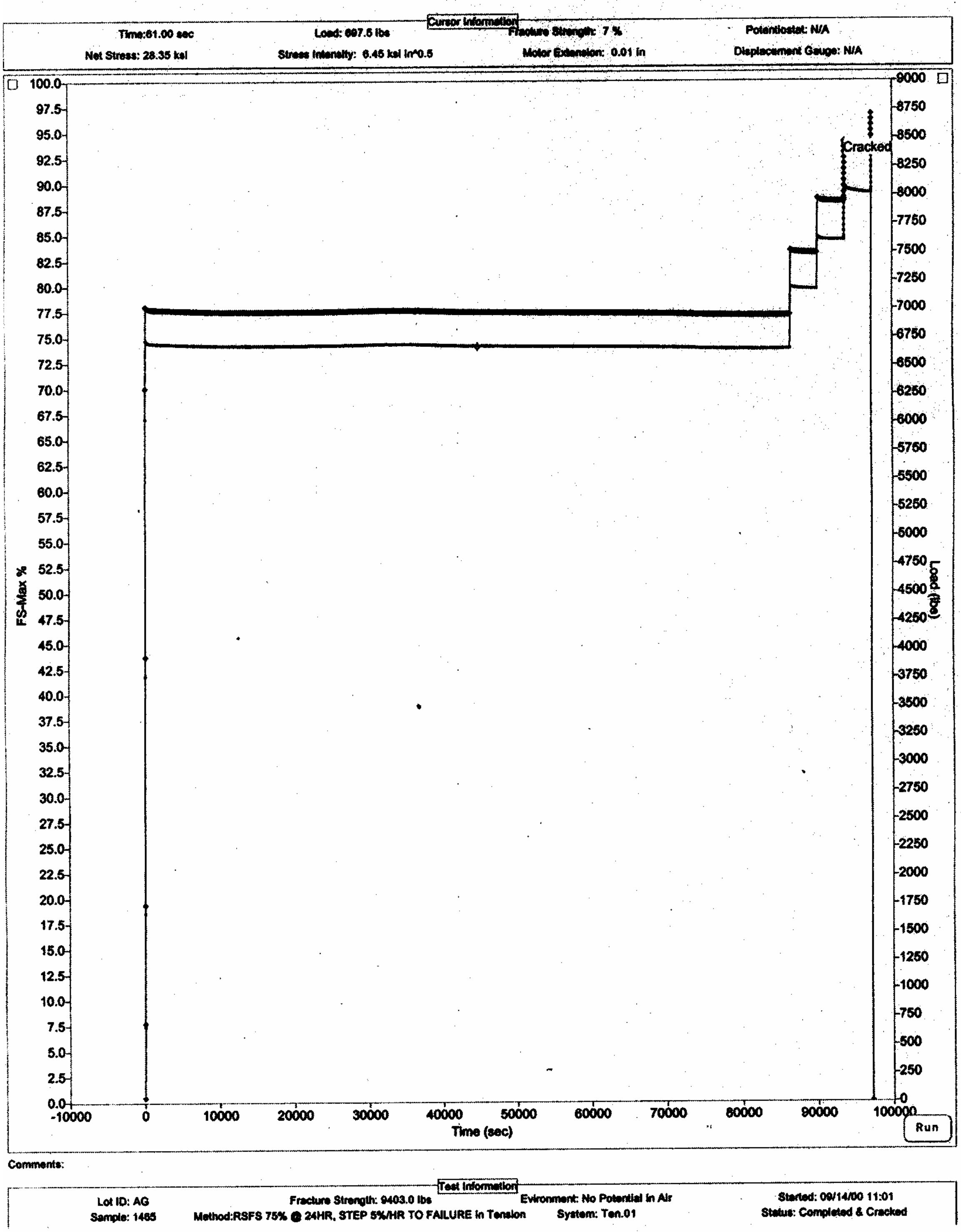
Step	Duration	Step %	Step Load	End Load	% Load Drop	Cumulative Time
1	24.0	75%	7052.3	6943.3	1%	24.0
2	1.0	80%	7522.9	7491.5	0%	25.0
3	1.0	85%	7992.9	7943.0	1%	26.0
4	1.0	90%	8465.1	8375.0	1%	27.0
5	1.0	0%	0.0	1.5	0%	27.0

Sample Cracked at 93% of Fracture Strength on Step 5

Test Executed By: ____________________
Craig Matzdorf

NAWC

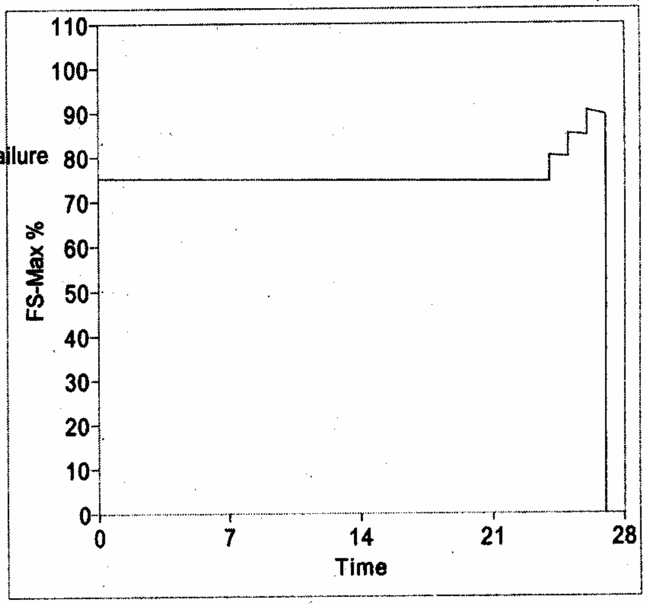
Page 1 of 1


Cursor Information
Time:61.00 sec
Load: 697.5 lbs
Fracture Strength: 7 %
Potentiostat: N/A
Net Stress: 28.35 ksi
Stress Intensity: 6.45 ksi in^0.5
Motor Extension: 0.01 in
Displacement Gauge: N/A
FS-Max %
Load (lbs)
Cracked
Time (sec)
Run
Comments:
Test Information
Lot ID: AG
Fracture Strength: 9403.0 lbs
Evironment: No Potential in Air
Started: 09/14/00 11:01
Sample: 1465
Method:RSFS 75% @ 24HR, STEP 5%/HR TO FAILURE in Tension
System: Ten.01
Status: Completed & Cracked

CP w WAFS

c:\rslsi\Craig Matzdorf\cp w wafs01.tst

Start Time:	12/06/00 17:27
Lot ID:	Al
Sample #:	2132
Sample Type:	Notched Round Bar
Method:	75%@24hr, step 5%/hr to failure
Test Type:	Tension
Tensile Strength:	391.3 ksi
Fracture Strength:	9412.0
Fracture Load:	8737.4
Fracture %:	92.8
End Time:	12/07/00 20:28
System:	Tens 01
Calibration Date:	12/03/00 09:28
Process ID:	CP w Fumitrol w 24hr bake
Batch:	Dirats/CP
Potential:	No Potential Applied
Solution:	Air



Comments:

Step	Duration	Step %	Step Load	End Load	% Load Drop	Cumulative Time
1	24.0	75%	7077.9	7002.9	1%	24.0
2	1.0	80%	7553.9	7527.2	0%	25.0
3	1.0	85%	8020.2	7977.3	0%	26.0
4	1.0	90%	8510.0	8417.6	1%	27.0
5	1.0	0%	0.0	4.3	0%	27.0

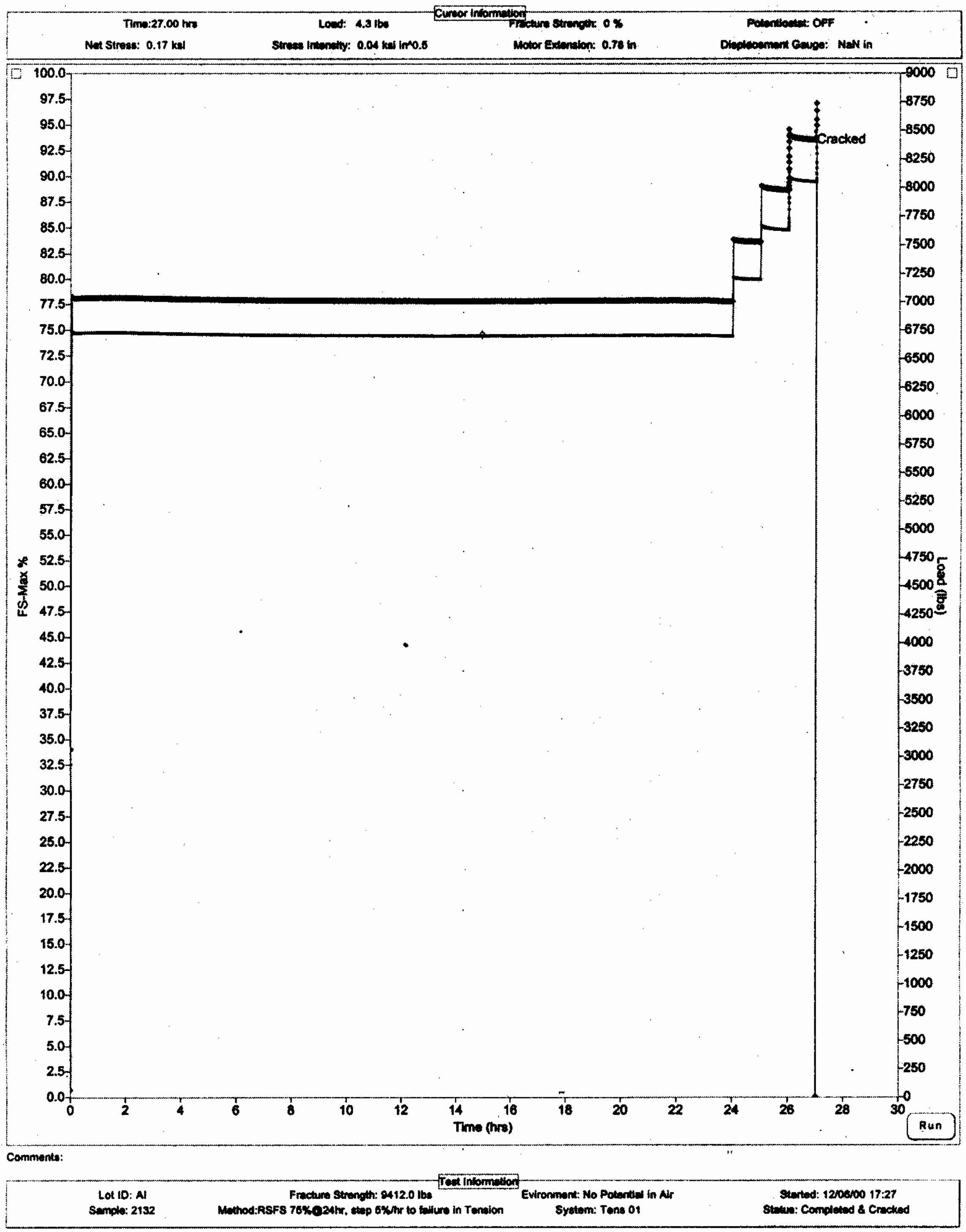
Sample Cracked at 93% of Fracture Strength on Step 5

Test Executed By:__________________

Craig Matzdorf

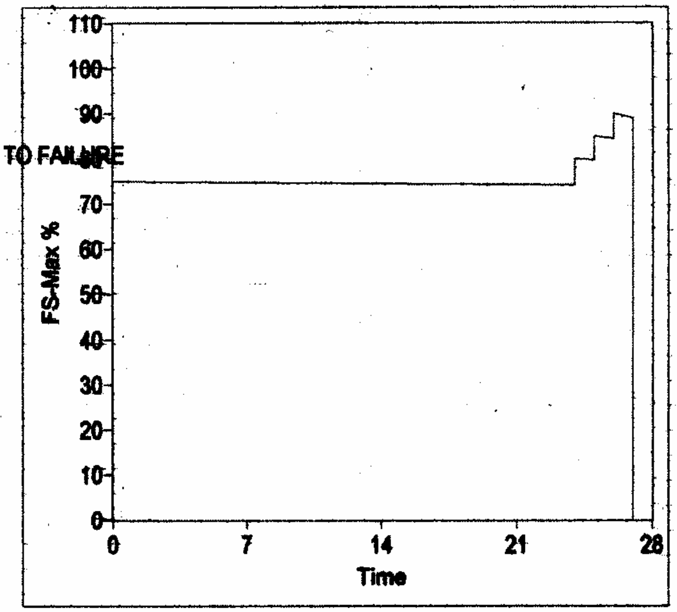
NAWC

Page 1 of 1


Cursor Information
Time:27.00 hrs
Load: 4.3 lbs
Fracture Strength: 0 %
Potentiostat: OFF
Net Stress: 0.17 ksi
Stress Intensity: 0.04 ksi in^0.5
Motor Extension: 0.78 in
Displacement Gauge: NaN in
FS-Max %
Load (lbs)
Time (hrs)
Cracked
Run
Comments:
Test Information
Lot ID: Al
Sample: 2132
Fracture Strength: 9412.0 lbs
Method:RSFS 75%@24hr, step 5%/hr to failure in Tension
Evironment: No Potential in Air
System: Tens 01
Started: 12/06/00 17:27
Status: Completed & Cracked

NI Fumitrol 140 c:\RSLSI\Craig Metzdorf\north island 01.tst

Start Time: 07/10/00 07:43
Lot ID: AG
Sample #: 1534
Sample Type: Notched Round Bar
Method: 75% @ 24HR, STEP 5%/HR TO FAILURE
Test Type: Tension
Tensile Strength: 390.9 ksi
Fracture Strength: 9403.0
Fracture Load: 8552.2
Fracture %: 91.0
End Time: 07/11/00 10:43
System: Ten.01
Calibration Date: 07/10/00 07:39
Process ID: Fumitrol 01
Batch: Dirats/NI
Potential: No Potential Applied
Solution: Air
Comments:



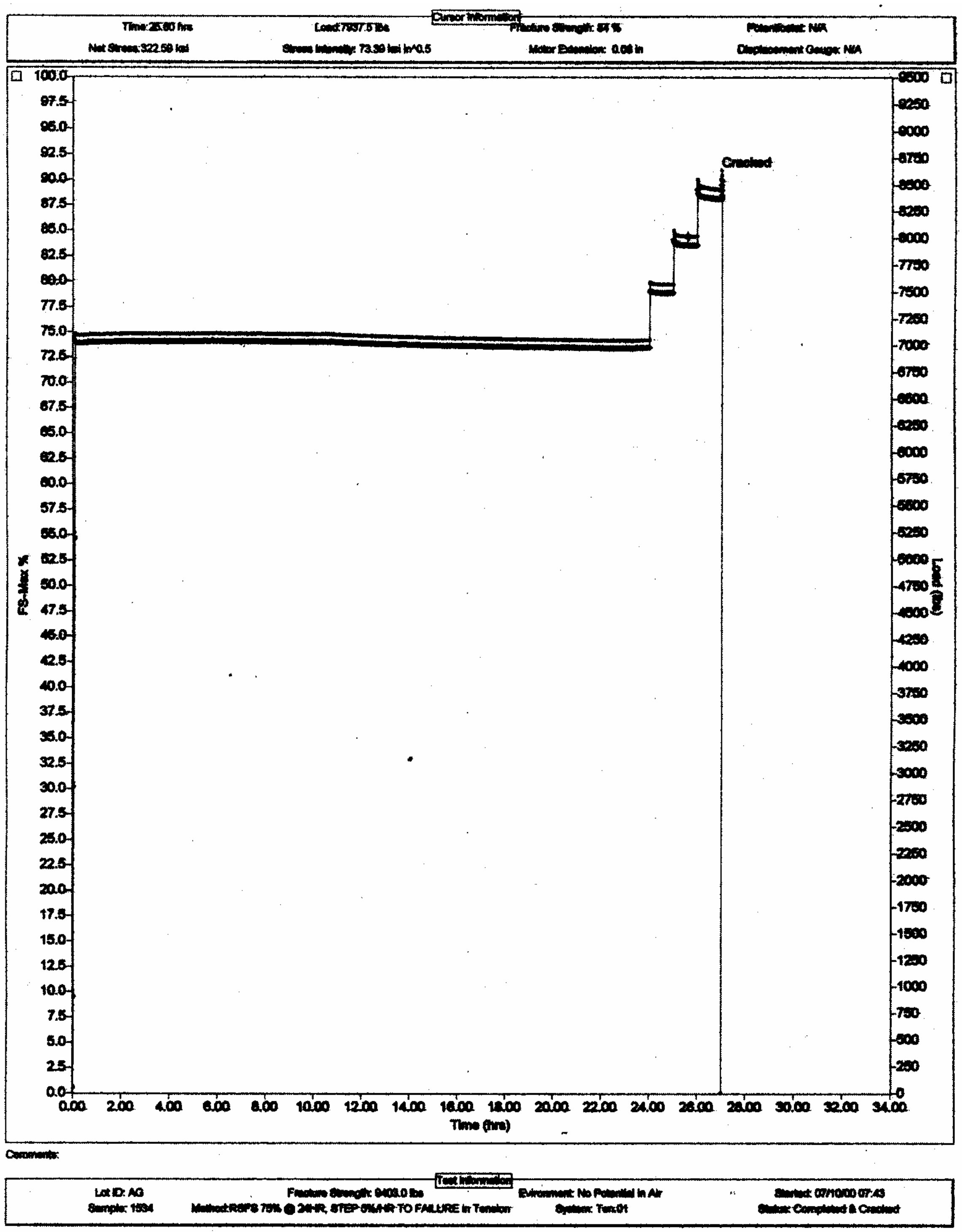
Step	Duration	Step %	Step Load	End Load	% Load Drop	Cumulative Time
1	24.0	75%	7054.5	6979.5	1%	24.0
2	1.0	80%	7522.9	7497.3	0%	25.0
3	1.0	85%	7992.8	7937.3	1%	26.0
4	1.0	90%	8463.6	8370.0	1%	27.0
5	1.0	0%	0.0	-0.6	0%	27.0

Sample Cracked at 91% of Fracture Strength on Step 5

Test Executed By:__________________
Dayle A. Conrad

Page 1 of 1

NAWCADPAX

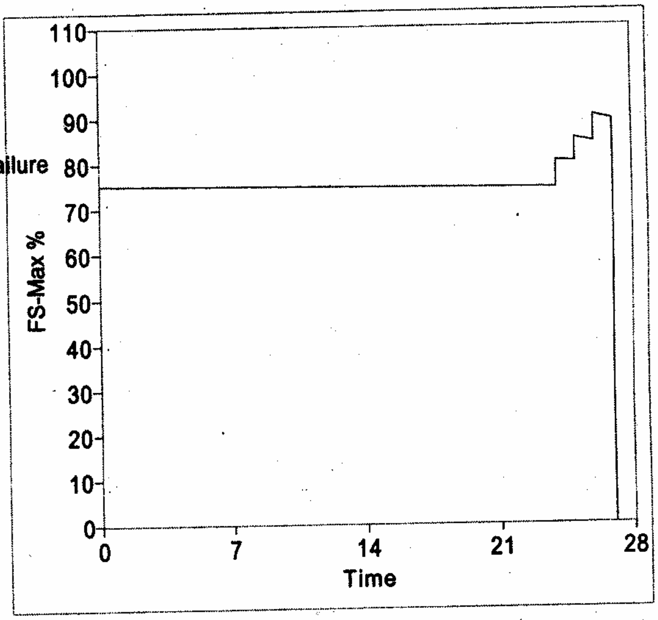


Cursor Information
Time: 25.60 hrs
Load: 7937.5 lbs
Fracture Strength: 84 %
Potentiostat: N/A
Net Stress: 322.59 ksi
Stress Intensity: 73.39 ksi in^0.5
Motor Extension: 0.08 in
Displacement Gauge: N/A
Cracked
FS-Max %
Load (lbs)
Time (hrs)
Comments:
Test Information
Lot ID: AG
Fracture Strength: 9403.0 lbs
Evironment: No Potential in Air
Started: 07/10/00 07:43
Sample: 1534
Method: RSPS 75% @ 24HR, STEP 5%/HR TO FAILURE in Tension
System: Ten:01
Status: Completed & Cracked

ALC Lot "A"

c:\rslsi\Craig Matzdorf\ALC lot A 01.tst

Start Time: 01/22/01 08:39
Lot ID: AG
Sample #: 1141
Sample Type: Notched Round Bar
Method: 75%@24hr, step 5%/hr to failure
Test Type: Tension
Tensile Strength: 390.9 ksi
Fracture Strength: 9403.0
Fracture Load: 8818.9
Fracture %: 93.8
End Time: 01/23/01 11:40
System: Tens 01
Calibration Date: 12/03/00 09:28
Process ID: ALC Lot "A"
Batch: Dirats/ALC
Potential: No Potential Applied
Solution: Air
Comments: Red rust on sample noted



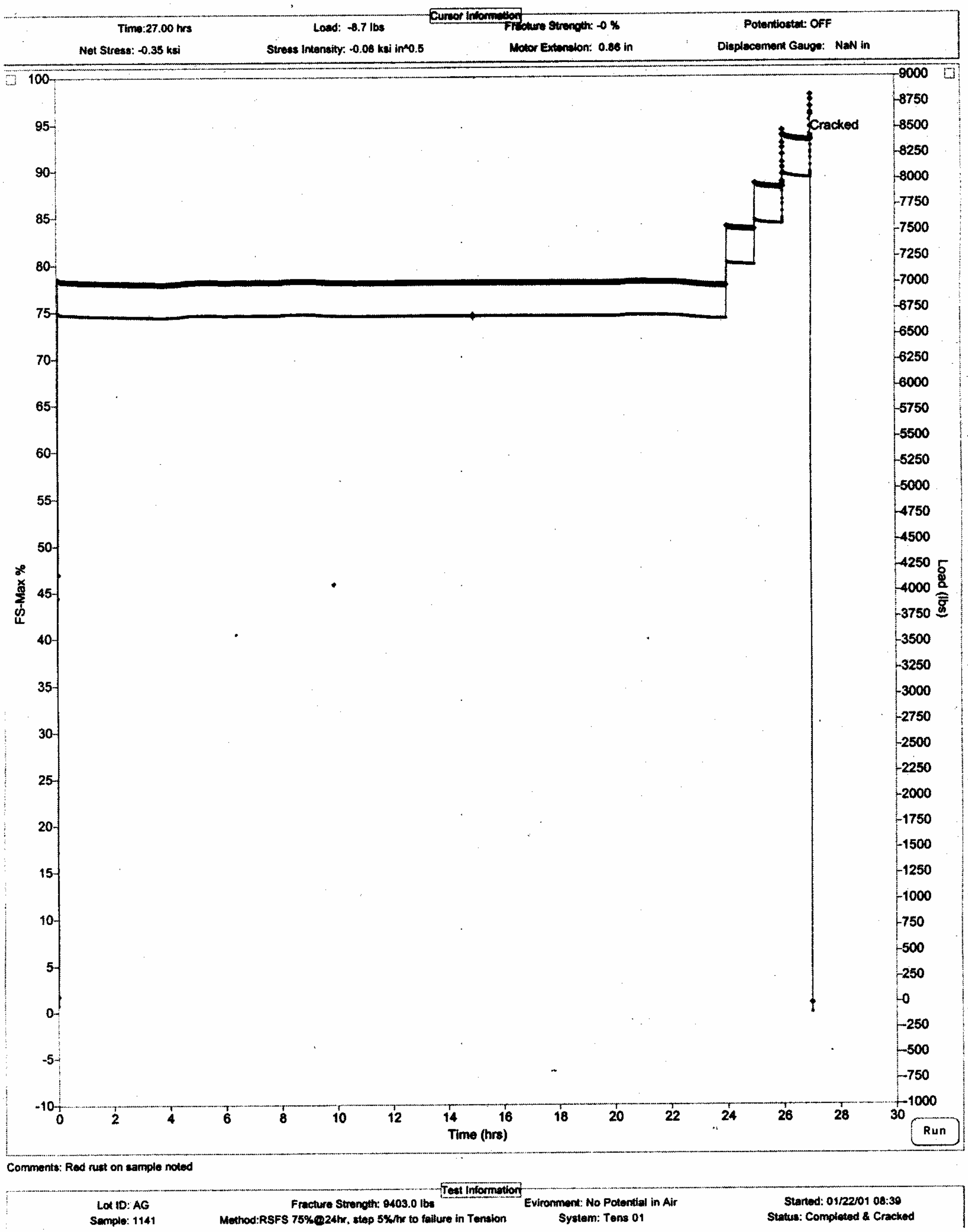
Step	Duration	Step %	Step Load	End Load	% Load Drop	Cumulative Time
1	24.0	75%	7072.8	6973.8	1%	24.0
2	1.0	80%	7536.0	7513.1	0%	25.0
3	1.0	85%	7997.9	7917.4	1%	26.0
4	1.0	90%	8476.1	8380.0	1%	27.0
5	1.0	0%	0.0	-8.7	0%	27.0

Sample Cracked at 94% of Fracture Strength on Step 5

Test Executed By:________________
ICL

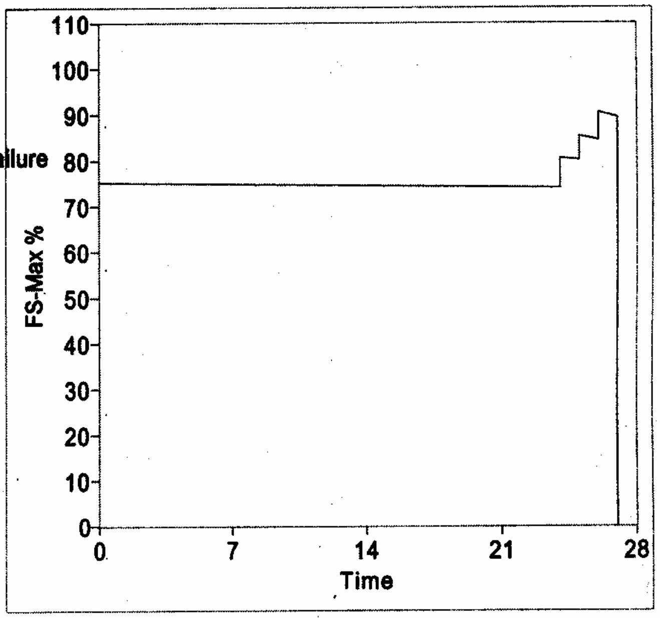
NAWC

Page 1 of 1


Cursor Information
Time:27.00 hrs
Load: -8.7 lbs
Fracture Strength: -0 %
Potentiostat: OFF
Net Stress: -0.35 ksi
Stress Intensity: -0.08 ksi in^0.5
Motor Extension: 0.86 in
Displacement Gauge: NaN in
Cracked
FS-Max %
Load (lbs)
Time (hrs)
Run
Comments: Red rust on sample noted
Test Information
Lot ID: AG
Sample: 1141
Fracture Strength: 9403.0 lbs
Method:RSFS 75%@24hr, step 5%/hr to failure in Tension
Evironment: No Potential in Air
System: Tens 01
Started: 01/22/01 08:39
Status: Completed & Cracked

ALC Lot "B"   c:\rslsi\Craig Matzdorf\ALC lot B 01.tst

Start Time: 02/08/01 08:27
Lot ID: AG
Sample #: 1314
Sample Type: Notched Round Bar
Method: 75%@24hr, step 5%/hr to failure
Test Type: Tension
Tensile Strength: 390.9 ksi
Fracture Strength: 9403.0
Fracture Load: 8517.6
Fracture %: 90.6
End Time: 02/09/01 11:27
System: Tens 01
Calibration Date: 12/03/00 09:28
Process ID: ALC Lot "B"
Batch: Dirats/ALC
Potential: No Potential Applied
Solution: Air
Comments:



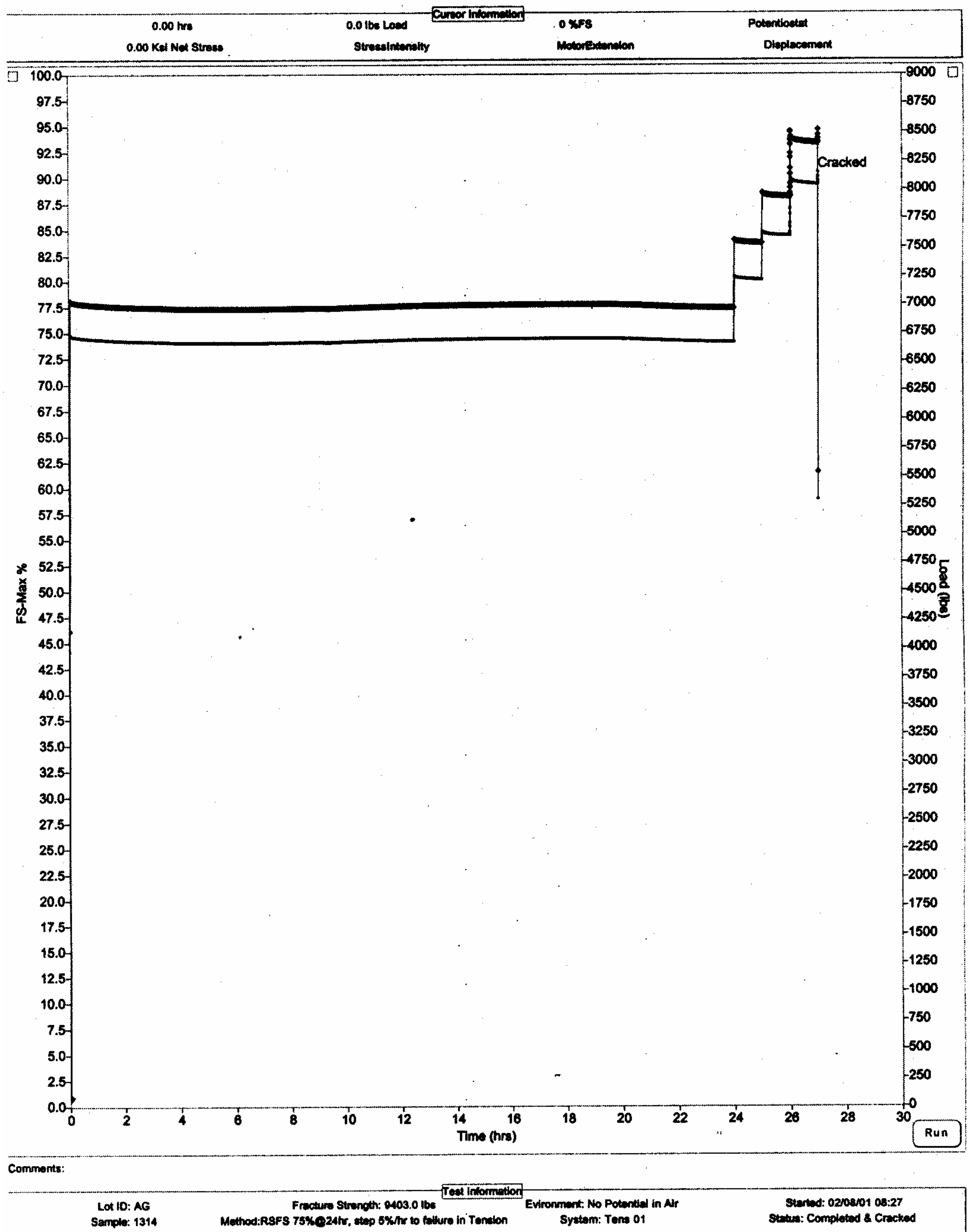
Step	Duration	Step %	Step Load	End Load	% Load Drop	Cumulative Time
1	24.0	75%	7074.6	6964.3	1%	24.0
2	1.0	81%	7570.8	7534.7	0%	25.0
3	1.0	85%	8019.5	7938.7	1%	26.0
4	1.0	90%	8504.2	8403.4	1%	27.0
5	1.0	0%	0.0	5538.4	-59%	27.0

Sample Cracked at 91% of Fracture Strength on Step 5

Test Executed By:_______________
ICL

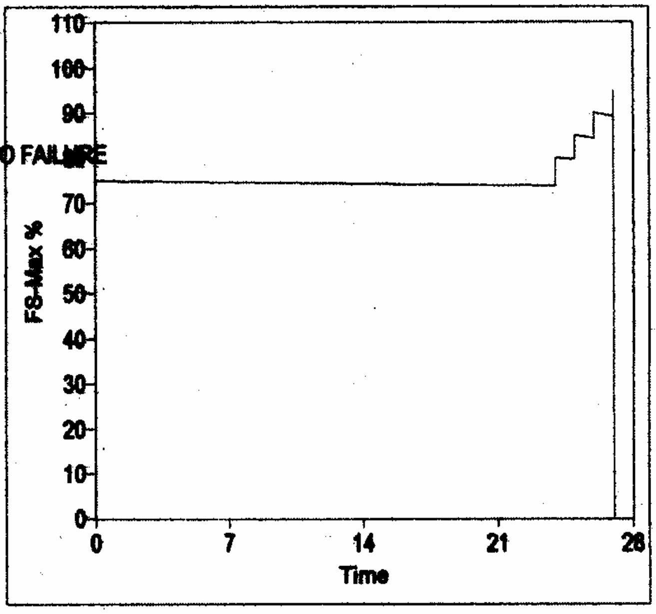
NAWC

Page 1 of 1


Cursor Information
0.00 hrs
0.0 lbs Load
0 %FS
Potentiostat
0.00 Ksi Net Stress
StressIntensity
MotorExtension
Displacement
FS-Max %
Load (lbs)
Time (hrs)
Cracked
Run
Comments:
Test Information
Lot ID: AG
Sample: 1314
Fracture Strength: 9403.0 lbs
Method:RSFS 75%@24hr, step 5%/hr to failure in Tension
Evironment: No Potential in Air
System: Tens 01
Started: 02/08/01 08:27
Status: Completed & Cracked

UNPLATED CONTROL 01 c:\RSLSI\Craig Matzdorf\control01.tst

Start Time: 06/26/00 14:44
Lot ID: AG
Sample #: 1144
Sample Type: Notched Round Bar
Method: 75% @ 24HR, STEP 5%/HR TO FAILURE
Test Type: Tension
Tensile Strength: 390.9 ksi
Fracture Strength: 9403.0
Fracture Load: 8938.0
Fracture %: 95.1
End Time: 06/27/00 17:46
System: Ten.01
Calibration Date: 06/26/00 14:38
Process ID: UNPLATED CONTROL
Batch: DIRATS
Potential: No Potential Applied
Solution: Air
Comments:

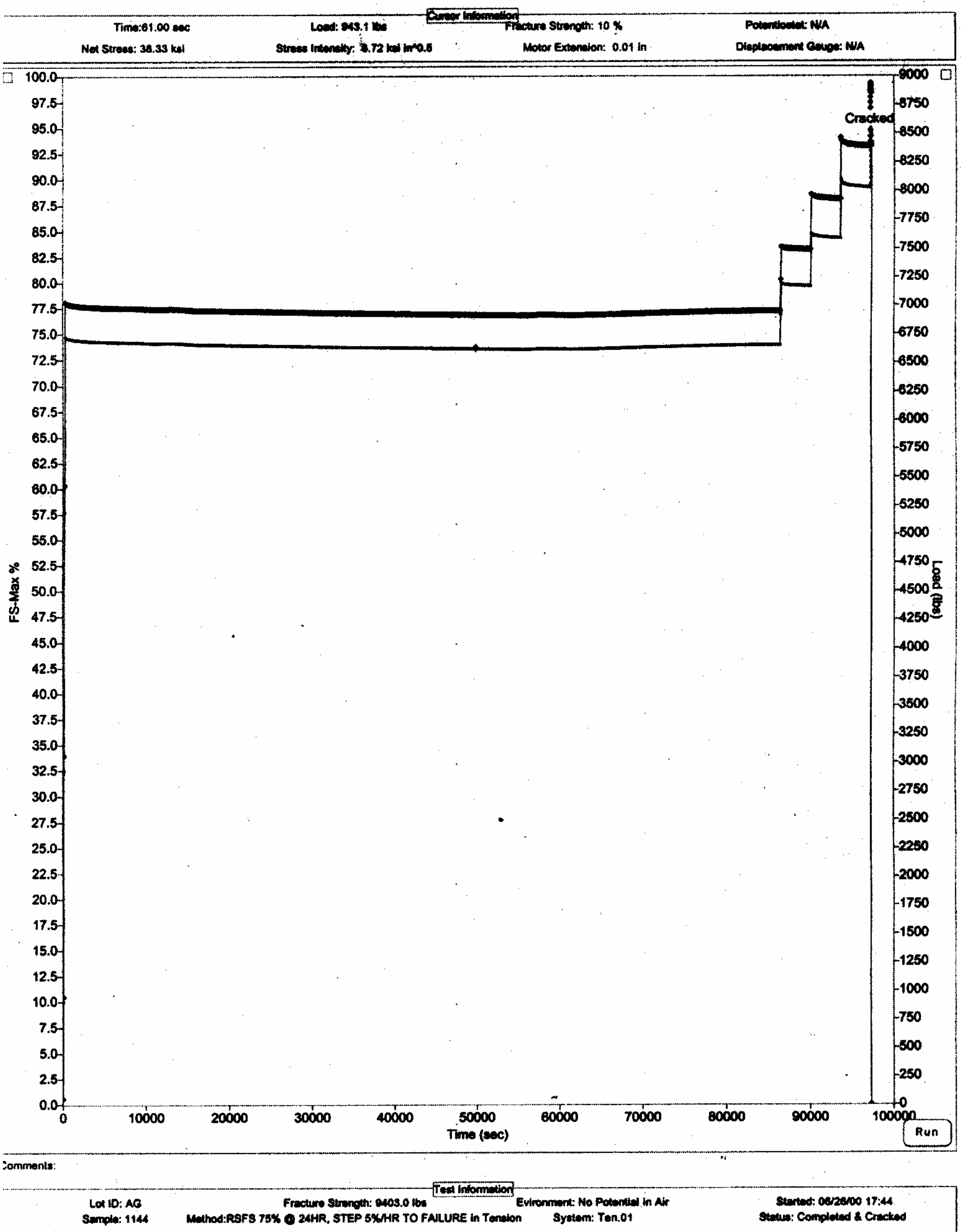


Step	Duration	Step %	Step Load	End Load	% Load Drop	Cumulative Time
1	24.0	75%	7053.0	6948.0	1%	24.0
2	1.0	80%	7523.0	7491.3	0%	25.0
3	1.0	85%	7995.9	7926.8	1%	26.0
4	1.0	90%	8466.3	8387.5	1%	27.0
5	1.0	95%	8938.0	1.8	95%	27.0

Sample Cracked at 95% of Fracture Strength on Step 5

Test Executed By:________________
Dayle A. Conrad
NAWCADPAX

Page 1 of 1



Cursor Information
Time:61.00 sec
Load: 943.1 lbs
Fracture Strength: 10 %
Potentiostat: N/A
Net Stress: 38.33 ksi
Stress Intensity: 8.72 ksi in^0.5
Motor Extension: 0.01 in
Displacement Gauge: N/A
FS-Max %
Load (lbs)
Cracked
Time (sec)
Run
Comments:
Test Information
Lot ID: AG
Sample: 1144
Fracture Strength: 9403.0 lbs
Method:RSFS 75% @ 24HR, STEP 5%/HR TO FAILURE in Tension
Evironment: No Potential in Air
System: Ten.01
Started: 06/26/00 17:44
Status: Completed & Cracked

APPENDIX H

ALTERNATIVE INDUSTRIAL HYGIENE SAMPLING RESULTS

ALTERNATIVE INDUSTRIAL HYGIENE SAMPLING DATA - also see NOTES
(concentrations in micrograms/cubic meter)

CHERRY POINT				TINKER			
	Hexavalent Chromium Concentration				Hexavalent Chromium Concentration		
Test Date	Remote Breathing Zone	Near Tank Breathing Zone	In Tank	**Test Date**	Remote Breathing Zone	Near Tank Breathing Zone	In Tank
7/11/00	0.041	1.81	1.450	9/12/00 am	0.115	15.8	0.201(note 3)
7/12/00	0.033	0.077	1.250	9/12/00 pm	(note 4)	0.022	0.252
9/21/00 am	0.031	0.024	0.023	10/11/00 am	0.007	0.035	0.023
9/21/00 pm	(note 4)	0.043	0.043	10/11/00 pm	(note 4)	0.028	0.033
11/15/00 am	0.056	0.112	2.266	11/8/00 am	0.047	0.014	0.036
11/15/00 pm	(note 4)	(note 4)	2.400	11/8/00 pm	(note 4)	(note 4)	0.078
11/16/00 am	0.042	0.035	0.070	12/6/00	0.028	0.042	0.100
11/16/00 pm	(note 4)	(note 4)	0.120	7/31/01	0.023	0.038	0.053
12/13/00 am	0.014	0.030	0.113	8/1/01 (note 5)	0.050	0.018	16.42
12/13/00 pm	(note 4)	0.030	0.075				
3/27/01	0.014	0.186	0.073				
4/17/01	0.028	0.014	0.041				
Averages[6]:							
without FS:	**0.043**	**0.667**	**1.68**		**0.083**	**3.96**	**8.32**
with FS:	**0.026**	**0.060**	**0.067**		**0.026**	**0.031**	**0.060**

NOTES:

1 - Rows with shaded background represent baseline data (i.e., without fume suppressant [FS]).

2 - All values reported below various detection limits were averaged as the detection limit divided by the square root of 2 (i.e., 1.414).
For example: if non-detect was less than 0.020 mic/cu.m. then it was reported as 0.014 (i.e., 0.020/1.414) - see reference 5.

3 - For Tinker, a value of 585 mic/cu.m. was considered an outlier from the 9/12/00 am sampling for "In Tank", and was not included in the calculations.

4 - Only one set of samples was taken during the day, spanning the entire day (i.e., am plus pm). The value shown for "am" represents the entire day.

5 - This baseline sample was taken on Tank 214. All other data were for Tank 222.

6 – To calculate averages, concentrations based on a full-day sampling were given twice the weight as concentrations based on half-day sampling.

For REFERENCE:

1 - Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) is 100 micrograms per cubic meter (mic/cu.m.) as chromic oxide (52 mic/cu.m. as chromium).

2 - **Proposed** OSHA PEL ranges between 0.5 and 5 mic/cu.m.

3 - American Conference on Governmental Industrial Hygienists (ACGIH) Time Weighted Average (TWA) for water-soluble hexavalent chromium compounds is 50 mic/cu.m. as chromium.

4 - National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) for hexavalent chromium compounds is 1 mic/cu.m. as chromium.

5 - Navy Environmental Health Center (NEHC), Industrial Hygiene Field Operations Manual, Chapter 4, Section 8a.(3), page 4-22.